5G High-accuracy Localization

1 Theme: Wireless Communication Technology

2 Subject: 5G Communication Network

3 Background

User localization in 5G communication network is of increasing importance for safety, gaming, driving, location-based advertisement, and location-based social networking. The location awareness applications will enable ubiquitous and context aware network services which necessitate the location of the mobile device to be accurately estimated.

NGMN and 3GPP have defined the requirements of localization for future 5G applications. The objective location accuracy of 5G will be much stricter than LTE system. The accuracy ranges from a few meters in general outdoor to several centi-meters for the applications of unmanned driving and remote medicals, with positioning reliability of 99.9%. Since the evaluation of the currently available positioning technology for LTE achieves about 50 m of accuracy in 90 percent of occasions under perfect time and phase synchronization, the positioning technology and synchronization accuracy available today need significant improvements.

5G offers concepts that could be used to increase positioning accuracy, such as broader bandwidth (100MHz in sub-6GHz and >100MHz in above-6GHz), dense infrastructure (more LOS conditions, better geometry of the positioning solution), and data from a number of sensors and technologies (GNSS, WiFi, relative device-to-device positioning, inertial measurements, etc.). Combining all available signals into a very precise hybrid positioning system using cloud technologies seems to be a very appealing concept.
4 Scope

A. Range-based algorithms: the topic studies the estimation algorithm to measure TOA, TDOA, AOA, TOF, by investigating the channel impulse responses (CIRs) from multiple antennas. Study the positioning algorithms based on the above measurements.

B. RFP-based algorithms: the topic studies the positioning algorithm based on the received channel features. Channel features can be CIRs, parameters derived from CIRs, RSRP/SNR, throughput etc. Position is identified by comparing the current channel features with existing measurements. Linear classification and non-linear classification algorithms should be investigated.

5 Expected Outcome and Deliverables

- Technical reports range-based algorithm for localization
- Technical reports of RFP-based algorithm for localization
- Related simulation platform with source codes and description
- 1~2 Invention/patents;

6 Acceptance Criteria

The partner with wireless localization testbed shall have the priority for cooperation. For indoor, the positioning accuracy should be sub-meters with signal bandwidth 100MHz, and 10cm-level with signal bandwidth >400MHz. For outdoor, the positioning accuracy should be less than 2 meters for 80% scenarios.

7 Phased Project Plan

Phase1 (~3 months): Take measurements by testbeds. Estimate the parameters (e.g. TDOA, TOA, AOA, TOF) by measurements. The scenarios include indoor office and outdoor urban. Provide measurement data.
Phase 2 (~5 months): Study the range-based algorithm. Provide research reports, and source codes.

Phase 3 (~4 months): Study the RFP-based algorithm. Provide research reports, source codes, and patent ideas.
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Without the written consent of Huawei Technologies Co., Ltd, this document cannot be distributed except for the purpose of Huawei Innovation R&D Projects and within those who have participated in Huawei Innovation R&D Projects.
Acoustically actuated ultra-compact magnetoelectric antennas

1 Theme: Wireless Communication Technology

2 Subject: High Frequency

List of Abbreviations

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<tbody>
<tr>
<td>NEMS</td>
<td>nanoelectromechanical system</td>
</tr>
<tr>
<td>ME</td>
<td>magnetoelectric</td>
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3 Background

- With the continuous evolution of wireless communication systems, more and more antenna for different application and frequencies need to be integrated in a limited space, e.g., cell phone. Compactness of the antennas becomes a key issue in system design; conventional electric small antennas generally takes about 1/10 wavelength size, and must be loaded the lumped element or its equivalent circuit.
- Further reduction of the size to 1/1000~1/100 lambda without too much additional components is quite challenging, consequently the novel antenna miniaturization technology is promising.

4 Scope

*Acoustically actuated magnetoelectric coupling radiation theory*

- Investigate acoustically actuated magnetoelectric coupling radiation physical principle, usable material or structure, related ultra compact antenna design methodology

*Ultra Compact antenna efficiency reinforcement*
Investigate based on ME coupling mechanism, the technique to improve its radiation efficiency;

5 Expected Outcome and Deliverables

- Technical reports of acoustically actuated ultra compact magnetoelectric coupling antenna technology;
- High radiation efficiency improvement technology for above antenna;
- Related simulation or design methodology

6 Acceptance Criteria

Technology reports covers almost present study, related technique aspects are covered, well logic organized, related ultra compact antenna design methodology is proposed.

High efficiency radiation methodology is proposed;

7 Phased Project Plan

Phase1 (~3 months): survey the state of the art and provide the related technical report.

Phase2 (~9 months): research on acoustically actuated ME coupling ultra compact antenna methodology and related efficiency reinforcement technique.
Advanced reference signal and estimator design

1 Theme: Wireless Communication Technology

2 Subject: Radio Transmission Technology

3 Background

To provide robust system performance and high quality wireless communication services in various scenarios, NR supports several kind of user specific pilots, e.g., demodulation reference signals (DMRS) for uplink and downlink, channel state information reference signal (CSI-RS), and sounding reference signals (SRS). As the massive multi-user multiple-input multiple-output (MU-MIMO) is one of the important scenarios considered in NR, the pilot signal interference between co-scheduled users will severely degrade the system performance, which thus is urgently needed to be solved. The reference signals in NR occupy huge amount of resources. The RS overhead will scale with the number of scheduled UEs/streams. Advanced sequence design may be an efficient solution to the problem.

On one hand, orthogonal training sequences help reduce the interference. However it comes at the cost of large overhead. On the other hand, non-orthogonal sequences enable the gNB to transmit more streams in the limited time-frequency resource. Yet it suffers from the poor quality of channel estimation, and consequently the reduced quality of service. Therefore, advanced RS designs and channel estimation methods are required to enhance the estimation and/or reduce RS overhead.

This project aiming to design an advance RS scheme including estimator for massive MU-MIMO systems to provide orthogonality between pilots of MU as well as high spectrum efficiency, including advanced sequence design, corresponding channel estimator design, new RS pattern design, overhead reduction scheme and RS contamination elimination schemes.
4 Scope

A. Advanced sequence design: Instead of either orthogonal or non-orthogonal pilots (poor performance at large numbers of co-scheduled users), propose an advanced RS sequence design scheme, e.g., by designing sets with orthogonal & non-orthogonal sequences to guarantee hybrid feature of RS. Study different degrees of overloading to cater for varied transmission requirements.

B. Advanced Channel estimator: propose the advanced channel estimators for the advanced RS sequence generation and mapping to achieve high estimation accuracy as well as system performance.

C. Reference Signal overhead reduction and RS contamination elimination schemes, and new pattern: propose overhead reduction and RS contamination elimination schemes, and new pattern to balance estimation and capacity performance.

5 Expected Outcome and Deliverables

- Technical reports of the advanced RS sequence design scheme
- Technical reports of advanced channel estimator of advanced RS sequence design
- Technical reports of new RS pattern design of advanced RS sequence design
- Related simulation platform with source codes and description
- 1~2 Invention/patents

6 Acceptance Criteria

Reduce pilot overhead and signal interference between co-scheduled users in massive MU-MIMO scenarios and provide better system performance as well as high spectrum efficiency compared to current RS scheme.

For example, for uplink CSI acquisition in crowd scenarios, achieve higher system throughput than both orthogonal and non-orthogonal state-of-the-art pilot schemes. For
uplink CSI acquisition in multi-service scenarios, multiplex up to 5 times more simultaneous low-data-rate (LD) pilots, e.g. IoT, per RB while the broadband service class rate remains within 85% of its "single-service under-loaded" upper bound.

7 Phased Project Plan

- **Phase1 (~5 months):** Study the hybrid RS sequence design scheme. Provide research reports, source code, and patent ideas.

- **Phase2 (~4 months):** Study the advanced channel estimation scheme based on hybrid RS sequence design. Provide research reports, source code, and patent ideas.

- **Phase3 (~3 months):** Study the new Signal overhead reduction and RS contamination elimination schemes and new RS pattern of hybrid RS sequence to further improve system performance. Provide research reports, source code, and patent ideas.
AI/ML Based Physical Layer Optimization

1 Theme: Wireless Communication Technology

2 Subject: Physical Layer Algorithm

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<tr>
<td>AI</td>
<td>Artificial Intelligence</td>
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<tr>
<td>ML</td>
<td>Radio Link Failure</td>
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<tr>
<td>DL</td>
<td>Deep Learning</td>
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<tr>
<td>MIMO</td>
<td>Radio Resource Management</td>
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<tr>
<td>5G</td>
<td>5th Generation mobile network</td>
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3 Background

The prospects of 5G, the next generation of mobile network, have been discussed for years at the Mobile World Congress event in Barcelona. There are many advantages of 5G, the bandwidth, the low-latency and significant incensement of connections... All these advantages make 5G so desirable, but the problem is the extremely complex, non-linear computations to the physical layer that comes with them. In addition to all these complexities, the 5G definition is still not officially standardized. Meeting these demands requires a new approach, unlike anything before.

In the meantime, the AI or machine learning technologies has grown over many years, and now begins to deliver value to some domains. In wireless communication domain, in this year’s Mobile World Congress, CEVA's PentaG platform gave us a good example of applying AI to handle complex Chanel State Information (CSI) with challenging use cases.
We believe that there is a wide range of studies into DL and ML for communications and are excited at the possibilities this could lead towards future wireless communications systems. So, it is a valuable research direction to investigate the possibility to apply AI/ML approach in the 5G Physical Layer processing.

4 Scope

Explore Possibility of applying AI/ML in the physical layer processing

There are several reasons why AI/ML has the potential to provide gains over physical layer algorithms especially in 5G. The first is that the communication system is fundamentally a statistics system, while 5G introduced, the system is more and more complex to be modeled by the traditional information theory; the second, we might rethink the communication as an end to end system and apply the joint or cross layer optimizations; the third, as the AI algorithms are often unique or has the similar computation patterns, so in some cases the AI algorithms will be much more flexible; what’s more, there are many new emerging hardware design for AI computation, that might achieve the high power efficiency compare to the traditional SDR system.

In recent time, there are many ideas of AI applications in communication emerging, like auto encoders/decoders, MIMO detection, channel estimation, trained modulation, etc

We’d like to be open for the proposals, any proposal on the AI applications that would achieve significant higher wireless system performance, better power efficiency or more flexibility in the physical layer processing is welcome.

5 Expected Outcome and Deliverables

- Technical reports of the feasibility report of proposed specific AI applications in the physical layer processing;

- Technical reports of system architecture and algorithm design of the proposed AI applications ;
The data sets and benchmarks used to verify the proposed AI applications and comparison to the traditional algorithms.

The implementation codes and result report.

6 Acceptance Criteria

Propose and design the AI application in the physical layer processing area, finish the implementation and made the proof of the concept.

We can set the target in 2 ways:

- Compare to the traditional algorithm, the AI approach could improve the wireless system performance by 50%;
- Compare to the traditional algorithm, the AI approach could reduce the system complexity by 50%.

The proposed AI application should achieve at least one of them:

7 Phased Project Plan

Phase1 (~3 months): survey the state of the art of the relate research in the proposed area; the feasibility analysis and high level design;

Phase2 (~6 months): Detail design; common benchmarks and data set (Huawei could provide necessary support on preparing the data set); test result and analysis.

Phase3 (~3 months): Algorithm iteration, optimization and final report. Proposal for the future research directions and to do list.
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Distribution

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An AI-enabled Design of Wireless Transmitter-Receiver

1 Theme: Wireless Communication Technology

2 Subject: Radio Transmission Technology

3 Background

Artificial intelligence (AI) is the well known the enabling technology in domains such as computer vision and natural language processing by using machine learning (ML) or deep learning (DL), because it is difficult to characterize real world images or language and optimize the performance from a rigid mathematical view. In wireless communication, however, transmit signals can be designed to enable straightforward analytic algorithms for symbol detection and estimation in a variety of channel and system models (e.g., detection of a constellation symbol or channel decoding in additive white Gaussian noise (AWGN)). Hence, as long as such models sufficiently capture real effects, we do not expect to yield significant improvements on the physical layer.

Nevertheless, practical system has many imperfections and non-linearity (e.g., fading channel, non-linear power amplifiers, finite resolution quantization, etc.) that cannot accurately captured by mathematical models. Traditional baseband processing architecture with the chain of multiple independent processing blocks (e.g. channel codec, mod/demod, scrambling/descrambling, MIMO processing, etc.) has led to the efficient, versatile, and controllable systems, it is not clear that individually optimized processing blocks achieve the best possible end-to-end performance. However, a learned end-to-end communications system, does not require such a rigid modular structure as it is optimized for end-to-end performance. Therefore, we believe that the AI applications can also be used to rethink the communications system design problem by reconstituting the transmitter and receiver to break the traditional architecture or replacing complex processing blocks, and hold promise for performance improvements in complex communications scenarios that are difficult to depict with tractable mathematical models.
4 Scope

Identify the key technical problems and the feasibility for the application of the AI technology to the baseband architecture design, and propose an AI-enabled architecture, where an end-to-end link is designed to break the traditional architecture or partial processing blocks are enhanced by AI to significantly simplify the computational complexity. Either innovative system or legacy system (i.e., LTE, NR) could be the fundamental of the design.

5 Expected Outcome and Deliverables

- The state-of-the-art investigation report of baseband architecture based on the AI technology and the analysis of the key technical problems;
- Technical reports of how to propose and analyze the AI-enabled architecture and the corresponding key algorithms while guaranteeing the performance;
- Technical reports of simulation evaluation and experimental works concerning the entire architecture or partial processing blocks;

6 Acceptance Criteria

The state-of-the-art investigation report involves the identification of the key technical problems and the feasibility for the application of the AI technology to the transmitter and receiver design, or receiver alone for legacy transmitter (i.e., LTE, NR). The proposed link-level architecture or partial processing blocks would be analytically reasonable, and the simulation and experimental results are highly reliable.

7 Phased Project Plan

Phase1 (~3 months): Survey the state of the art of AI-enabled transmitter and receiver design in wireless networks in industry and academic, and identify the problems, compatibility, metrics and requirements in this topic, forms technical reports.
Phase 2 (~5 months): Research on AI-enabled architecture solution design, could be the end-to-end link design or the partial processing focused study. Form the solution design report and the simulation evaluation of the core idea and the corresponding algorithms.

Phase 3 (~4 months): Verify the feasibility of the proposed link-level architecture or partial key processing blocks using experimental data and form the corresponding test report.
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Analog receiver techniques for high-order modulation and ultra-wideband MIMO system

1 Theme: Wireless Communication Technology

2 Subject: High Frequency

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<tr>
<td>VR</td>
<td>Virtual Reality</td>
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<tr>
<td>MIMO</td>
<td>Multiple input Multiple output</td>
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<tr>
<td>ADC</td>
<td>Analog-to-Digital Converter</td>
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<tr>
<td>OFDM</td>
<td>Orthogonal Frequency Division Multiplexing</td>
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3 Background

The peak data rate of wireless link is considered to be hundreds Gbps, which will satisfy the requirement of multiple virtual reality (VR) users, multiple autonomous vehicles, etc. Then high resolution video and high precision map could be downloaded through wireless link to VR users and autonomous vehicles, respectively. To achieve the extremely high data rate, high-order modulation, ultra-wideband and multiple input multiple output (MIMO) are adopted. However, the traditional digital receiver puts the analog-to-digital converter (ADC) right after down-converter and analog filter. The sampling rate and resolution of the ADC should be extremely high, which is a huge challenge.

To overcome the challenge, analog receiver is a promising method, where synchronization, detection and demodulation could be processed in the analog domain. Then the sampling rate and resolution of the ADC could be highly reduced.
Therefore, it is a valuable research direction to investigate the analog receiver techniques for high-order modulation and ultra-wideband MIMO system.

4 Scope

Analog Receiver Architecture with High-order Modulation

Investigate the analog receiver architecture with high-order modulation. Try to increase the modulation order as high as possible, which could reduce the requirement of bandwidth and number of beams to achieve hundreds Gbps data rate.

Analog Synchronization, Detection and Demodulation with Single/Multiple Antennas using Single Carrier Signal

Investigate the analog synchronization, detection and demodulation with single/multiple antennas using single carrier signal.

Analog Synchronization, Detection and Demodulation with Single/Multiple Antennas using Orthogonal Frequency Division Multiplexing (OFDM) Signal

Investigate the analog synchronization, detection and demodulation with single/multiple antennas using OFDM signal.

5 Expected Outcome and Deliverables

- Survey report of the existed analog receiver schemes with high-order modulation, where the advantage/disadvantages of the schemes are compared;
- Design report of the analog receiver with high-order modulation, where includes the technical details;
- Simulation platform of the analog receiver with high-order modulation, which could be used to evaluate the system performance;
- 1~2 Invention/patents for the innovative analog receiver architecture or scheme;
6 Acceptance Criteria

Design competitive analog receiver for high-order modulation and ultra-wideband MIMO system, which performance is at least not worse than LTE;

7 Phased Project Plan

Phase1 (~3 months): survey the state of the art of analog receivers

Phase2 (~6 months): research on analog synchronization, detection and demodulation with single/multiple antennas using single carrier signal or OFDM signal, provide reports and simulation platform

Phase3 (~3 months): research and provide related algorithms, simulation results and patents.
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Application defined transistor model extraction

1 Theme: Wireless Communication Technology

2 Subject: High Frequency

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<tr>
<td>HEMT</td>
<td>High electron mobility transistor</td>
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<tr>
<td>HBT</td>
<td>Heterojunction bipolar transistor</td>
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3 Background

- Compound semiconductor technology including HEMT/HBT, still shows performance competition in microwave and millimeter wave application.

- The foundry typically provide their own general transistor model, which helps designer to initialize MMIC design. But their model shows non-uniform accuracy in different function blocks design, e.g. PA, mixers/tripler, attenuator and oscillator. Especially nonlinear parameter simulation (e.g. IP3, P1, Harmonic suppression) show much higher deviation from test result.

- Further study to match transistor model with dedicated application is important.

4 Scope

PA related transistor model error analysis

- Investigate typical error contribution of HEMT/HBT model for class A/AB/B/Doherty, propose improve method including model selection, test method, etc.

Mixer/Attenuator/Frequency multiplier related transistor model error analysis
• Investigate main error contribution of HEMT model for typical mixer/attenuator/frequency multiplier, propose improve method including model selection, test method, etc.;

5 Expected Outcome and Deliverables

• Technical reports of general compound semiconductor HEMT/HBT transistor model and its extraction methodology;
• PA related transistor model error analysis report;
• Mixer/Attenuator/Frequency multiplier related transistor model error analysis

6 Acceptance Criteria

Technology survey reports covers almost present study, related technique aspects are covered, well logic organized;

Dedicated application related transistor model error analysis is clear;

Improve method is well proposed:

7 Phased Project Plan

Phase1 (~4 months): survey general compound semiconductor HEMT/HBT transistor model and its extraction methodology, and Investigate typical error contribution of HEMT/HBT model for class A/AB/B/Doherty, propose improve method.

Phase2 (~9 months): Investigate main error contribution of HEMT model for typical mixer/attenuator/frequency multiplier, propose improve method including model selection.
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Behavior Model and Characteristics of Non-Circulator
High-efficiency Power Amplifier in Massive MIMO System

1 Theme: Wireless Communication Technology

2 Subject: High efficiency Power Amplifier

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<tr>
<td>MIMO</td>
<td>Multiple-Input Multiple-Output</td>
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<tr>
<td>PA</td>
<td>Power Amplifier</td>
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</table>

3 Background

The volume and cost of the circulator in the MIMO system account for a large proportion of the RF front-end, and removing the circulator can generate great benefits. However, due to the impact of the array active load pulling effect after the removal is mainly shown as the following:

1. Changes in load of PA may introduce the stability problem of the system, even reliability issue;

2. Due to the load change, the PA performance deviates from its optimal power, linearity, and efficiency.

3. The system EIRP and pattern deterioration due to changes in PA phase and amplitude.

The elimination of circulators in the current MIMO system has a greater impact on the PA performance and the overall system. So, new power amplifier models and solutions need to be studied.
4 Scope

Under reflection coefficient of 0.5, the power amplifier model is able to achieve the following performance:

1. The distortion in AM-AM < 0.5dB (Power sweep from linearity to P-3 dB)
2. The distortion in AM-PM < 0.5dB (Power sweep from linearity to P-3 dB)
3. The variation in efficiency < 3%
4. Linearity: Transient signal bandwidth = 1 GHz in High Frequency and Transient signal bandwidth = 200MHz in sub6GHz.
5. The model should include memory effect terms.

5 Expected Outcome and Deliverables

- Methodological reports of Non-circulator high efficiency power amplifier behavior model extraction in Massive MIMO systems;
- Solution to the Non-circulator RF system;
- Deliverables:
  1. Document of “Non-circulator high efficiency power amplifier behavior model in Massive MIMO systems”
  2. Solution feasibility analysis to meet the requirements of cooperation project specifications

6 Phased Project Plan

Phase 1 (~6 months): Specification Analysis and Design

Goal: Deliver the report of feasibility analysis and design solutions.
Phase 2 (~4 months): Solution Design and Simulation, Testing, Summary and Reporting.

Goal: Verify design solution and test results.
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Communication and Computing Integrated Wireless Network

1 Theme: Wireless Communication Technology

2 Subject: Radio Transmission Technology

Keywords: Communication and Computing, Internet of Everything, Cloud and Fog

3 Background

The “Internet of Everything” has been proposed as a future step of IoT, where massive number of energy and complexity constrained devices should be connected to the network. Such devices are expected to have ultra long standby for up to several years, with very limited computing capabilities. In the current communication system, the baseband and protocol stacks consume a large amount of computing and storage resources. This includes modulation, coding, signal processing, resource allocation, routing, etc. Future wireless network should be more intelligent to adaptively handle more complex scenarios. This requires much higher computing capabilities.

Mobile Edge Computing (MEC) has attracted a lot of interest in recent years. C-RAN has been successfully applied to 5G where the wireless protocol stacks and baseband of Base Stations (BSs) are handled at cloud data centers. However, the diversity of User Terminals (UEs) in future wireless network have different computing, storage and energy capabilities. Complex computing tasks within UEs are expected to be handled at the network edge and delivered to UEs with minimal latency. Fog computing has been proposed to future extend the edge cloud to mobile network nodes, including BSs, APs, routers, switches, etc. With computing capability integrated, effective delivery of computing tasks from UEs to edge nodes is a promising solution to energy and computing constrained UEs.
4 Scope

The target of this project is to investigate novel network architecture, wireless interfaces, joint edge computing and communication algorithms supporting ultra flexible processing of computing tasks for energy constrained IoT devices. A conceptual diagram is as follows:

The project contains following stages of research:

1. Computational cost analysis of wireless communications for IoT devices

   Computational cost of different processing tasks in wireless communication should be analyzed, such as coding, modulation, signal processing, resource allocation, etc. Potential Artificial Intelligence (AI) assisted wireless algorithms should be considered, i.e. AI based decoding, channel estimation, resource assignment. Elastic protocol stack on UEs should be developed to support online transfer of computational task to the network.

2. Wireless edge architecture and interfaces supporting elastic computing for IoT UEs

   Radio access nodes and network devices should have computing capabilities for general wireless tasks. Wireless architecture and protocol should be redesigned to support the assignment of computation task and delivery of results between UE and network, and also between different network nodes.

3. Computing and communication assignment algorithms for IoT UEs

   The algorithms for assigning different UE computing tasks to network nodes should consider the optimization of computing cost on edge nodes and communication cost on
wireless link. Moreover, the delay of obtaining requests, assign tasks and delivering results to UEs should be minimized.

5 Expected Outcome and Deliverables

- The state-of-the-art investigation report of computing tasks in PHY, MAC and upper layers considering potential machine learning applications, with deep analysis of computing costs in time, iterations and energy.

- Technical reports of novel wireless architecture and air interface protocols, which supports computation request, task assignment, joint processing and result delivery between UE and multiple network nodes.

- Develop intelligent computing and communication assignment algorithms in wireless edge network. Optimize computing cost on edge nodes and communication cost on wireless link. Minimize the delay and energy consumption on an end-to-end cycle.

- System level simulation of communication and computing integrated wireless network. The simulator should contain full protocol stacks and air interfaces, with the capability of transferring wireless computational tasks from UE to edge network.

6 Acceptance Criteria

- The proposed novel network architecture and air interface protocols should support the concept of computation and communication integrated network, which should be demonstrated in system level simulations.

- The mathematical models and algorithms of scheduling different computational task from UE to network edge nodes should be realistic to wireless problems. Performance gain of UE energy consumption and computing cost should be achieved;

- Full demonstration of a computing and communication integrated network, with the capability of handling flexible computing for UEs and performance gain in line with analytical results.
• Publications of novel algorithms for handling UE computing tasks in network;
• Patents of protocol enhancement for transferring UE computing tasks to network.

7 Phased Project Plan

Phase1 (~3 months): Analyze the state of the art of PHY, MAC and upper layers computational task in UEs. Analyze the computing cost including energy, iterations and time. Investigate possible refinement in architecture and protocols supporting flexible transfer of computing tasks from UEs to network edge.

Phase2 (~4 months): Study novel architecture and air interface protocols in supporting computation and communication integrated network. Development of elastic RAN protocol stack for UE which supports transferring computation cost tasks to network edge.

Phase3 (~5 months): Develop mathematical models and algorithms of assigning computing tasks to different network nodes. Wireless information extraction in time and spatial domains should be considered for various communication algorithms. Energy, delay, communication and computing cost should be minimized.
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Without the written consent of Huawei Technologies Co., Ltd, this document cannot be distributed except for the purpose of Huawei Innovation R&D Projects and within those who have participated in Huawei Innovation R&D Projects.
Coverage Enhancement and Continuous Coverage Scheme for High-frequency Network

1 Theme: Wireless Communication Technology

2 Subject: Architecture and Resource Management

3 Background

Mm-wave play an important roles in 5G network. The plenty of spectrum in high frequency provide the possibility to meet the extreme high data rate requirements of 5G. However the channel characteristics of mm-wave, including large path loss, enlarged noise power (due to large bandwidth), large penetration loss and narrow beams, make continuous mm-wave coverage a great challenge, especially for NLOS scenario.

4 Scope

4.1 is required, and one can be chosen from 4.2 and 4.3.

4.1 Continuous Coverage Scheme

Research on the best network topological architecture (it is possibly oriented to scenario) for mm-wave standalone networking, design scheme for continuous coverage of mm-wave.

4.2 Coverage Enhancement

Research on coverage enhancement solution for mm-wave coverage, including but not limit to hybrid weight design, waveform design, advanced receiver and amplifier efficiency improvement, etc.

4.3 User Experience Improvement

Research on user experience improvement for mm-wave, including but not limit to: inter-cell coordination, mobility management, quick & robust beam selection, quick & robust cell handover, etc.
5 Expected Outcome and Deliverables

- Technical reports of coverage enhancement or continuous coverage scheme;
- Related simulation platform with source codes and description

6 Acceptance Criteria

Continuous coverage solution for mm-wave standalone networking, which will have a better coverage performance than the benchmark (according to the networking setting defined in 3GPP 38.802 TableA.2.1-1) by at least 10% in dense urban scenarios (provided by Huawei).

7 Phased Project Plan

Phase1 (~3 months): Survey the state of the art of continuous coverage and coverage enhancement/user experience improvement of mm-wave network. Provide the related technical report.

Phase2 (~5 months): Research on schemes of continuous coverage and provide the related technical report.

Phase3 (~4 months): research and provide related algorithms, simulation results and patents.
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Downlink Channel Reconstruction of FDD Massive MIMO System

1 Theme: Wireless Communication Technology

2 Subject: Radio Transmission Technology

3 Background

Uplink and downlink instantaneous channel do not have reciprocity in FDD system, so traditional FDD system exploits downlink quantitative feedback to obtain downlink channel information. However, FDD uplink and downlink channel has some intrinsic properties (e.g. multipath angle reciprocity). With massive MIMO application in FDD system, many researchers design transmission schemes by using the intrinsic properties to obtain downlink channel information. Unfortunately, under the limited conditions of actual systems and non-ideal estimations, the performances of these schemes are not obvious.

Therefore, in order to achieve good performances in actual FDD system, it is valuable research topic to investigate downlink channel reconstruction algorithms based on uplink channel state information and limited downlink quantitative feedback.

4 Scope

Downlink Channel Reconstruction Algorithm Design

Investigate the downlink Channel reconstruction algorithm based on uplink channel characteristics and limited downlink feedback.

Downlink Channel Reconstruction Algorithm Complexity and Upper Bounds Performance

Investigate how to reduce algorithm complexity and the upper bounds of the algorithm performance.
Downlink Channel Reconstruction Algorithm Simulation Performance

Investigate the downlink channel reconstruction algorithm performance in actual FDD massive MIMO system (such as under the limited base-station antenna number (64Tx) -Base station antenna topology: 4 rows 8 column +-45° polarization).

5 Expected Outcome and Deliverables

- The channel reconstruction algorithm theory derivation in FDD Massive MIMO system
- Technical reports of algorithm complexity analysis
- Technical reports of algorithm simulation performance in FDD Massive MIMO system
- Related simulation platform with source codes and description

6 Acceptance Criteria

Propose channel reconstruction algorithm considering both complexity and good performance in FDD massive MIMO system.

7 Phased Project Plan

Phase1 (~3 months): survey the state of the art of channel reconstruction algorithm based on uplink channel characteristics, analyze and provide the related technical report.

Phase2 (~6 months): propose reconstruction algorithm and provide the related technical report.

Phase3 (~3 months): research and provide related algorithms, simulation results and patents.
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Without the written consent of Huawei Technologies Co., Ltd, this document cannot be distributed except for the purpose of Huawei Innovation R&D Projects and within those who have participated in Huawei Innovation R&D Projects.
Efficient learning using generative adversarial network in wireless environment

1 Theme: Wireless Communication Technology

2 Subject: Future Network

3 Background

In 5G networks, the communication system is very complex with different RATs, different bands and different slices. Some intelligent technologies such as machine learning and neural network are used in resource management and parameter optimization to adapt to the changes in the wireless environment. Furthermore, reinforcement learning is also applied in the wireless system to improve KPI based on observed states of the network and the reward system.

However, inefficiency in training time is a difficult problem when applying learning algorithms in wireless systems. One way to solve this problem is to simple the network model or to reduce the input dimension. But this method will also decrease the precision of the algorithms. Another way is using Generative Adversarial Network (GAN). Although this technology is not very mature in wireless systems, the feature of GAN is very suitable for training.

So, it is a valuable research direction to investigate the Generative Adversarial Network technique using in wireless communication systems to speed up the training process.

4 Scope

- Investigation and analysis of the current research on using GAN in wireless systems or related systems, including pros and cons, valuable scenarios and so on.
- Research on efficient GAN network structure design, including the Generator and Discriminator.
• Research and verification on using GAN in training process of Artificial Intelligence algorithms.

5 **Expected Outcome and Deliverables**

• 1 survey reports on GAN research, especially in wireless networks;
• 1-2 research reports on structure design of GAN network in wireless systems, including the Generator and Discriminator;
• 2 algorithms analysis reports and verification about proposed algorithms using GAN;
• 1-2 patents and 1 publication submission.

6 **Acceptance Criteria**

Survey Report: Comprehensive study of the subject.
Research Report/Algorithm Report: Technical solution can be implemented. Clear technological advancement can be proved. Clear algorithm advancement can be proved.
Patent Proposal: Patent proposals are evaluated and accepted by the internal Huawei patent evaluation.
Publication: Paper written and submitted to a prestigious conference.

7 **Phased Project Plan**

Phase1 (~2 months): survey the state of the art of GAN research, especially in wireless networks.
Phase2 (~5 months): research on structure design of GAN network in wireless systems, including the Generator and Discriminator, and provide the related technical report.
Phase3 (~5 months):
research and provide related algorithms, simulation results and patents/publications.
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Energy Efficient 5G Architecture and Technology Investigation

1 Theme: Wireless Communication Technology

2 Subject: Energy Saving

3 Background

Energy consumption has become a major concern in design and operation of 5G system due to economics and environmental issue, with energy efficient emerged as a new prominent figure of merit. 5G systems have identified three scenarios including enhanced mobile broadband (eMBB), ultra-reliable low-latency communication (URLLC) and massive machine-type communication (mMTC). Although in eMBB scenarios, the per-bit energy consumption (J/bit) has been identified as the energy efficiency metric, there is no satisfied metrics for URLLC and mMTC scenarios, especially when the size of transmission packets is relatively small and the transmission delay requirement is stringent. In addition, 5G system is allowed to provide a large variety of different communication needs in the above scenarios over a shared physical network by network slicing, which will bring a challenge of energy efficient metric.
Another challenge in the energy efficient design for 5G systems is the resource management to allow the shared base station more times to enter idle and guarantee the different communication needs at the same time. Due to the different frame numerologies are designed to meet the variety use cases (low latency, high throughput, etc), it may be increase the active times of base station and the difficulty to enter into idle in time domain.

Moreover, the ever increasing number of processing chains in the base station side, such as massive multiple-input multiple-output (MIMO), ultra-dense networks (UDNs), millimeter wave communication, all involving multi-stream processing in huge dimensional spaces, increase associated signal processing power and the energy consumption in radio frequency chains are quite significant, which prevents from the commercialization of 5G communication systems.

4 Scope

Survey and propose the energy efficiency metric for 5G systems, especially focusing on ultra-reliable low-latency communication and massive machine-type communication scenarios.

Identify the research challenges in 5G systems, including but not limited to:

- Energy efficient resource management in multiple frequency bands, including Sub3G, Sub6G and mmWave in eMBB, URLLC, mMTC mix scenarios
- Energy efficient resource scheduling ,balancing the resources of the time domain, frequency domain, spatial domain to increase the idle time of base station in eMBB, URLLC, mMTC mix scenarios
- Massive signal processing in the spatial domain, e.g. massive MIMO, Massive signal processing in multiple frequency bands including mmWave or THz signals, massive signal processing with implementation aspects, e.g. hardware mismatch or distortion

Research on energy efficient enhancement solution design, including but not limited to:

Energy efficient resource management in mix scenarios, joint baseband and radio
frequency processing mechanisms, energy efficient pre-coding design for massive MIMO systems.

5 Expected Outcome and Deliverables

- Technical reports on energy efficiency metric design in 5G networks, especially for massive machine-type communication (mMTC) and ultra-reliability low-latency communications (URLLC).

- The state-of-the-art investigation report of energy efficient 5G architecture and technology with energy efficient resource management in mix scenarios and massive processing chains, including but not limited to massive MIMO systems, massive IoT processing.

- Technical reports on energy efficient enhancement solution design, including but not limited to energy efficient resource management, joint baseband and radio frequency processing mechanisms, energy efficient pre-coding design for massive MIMO systems, as well as the performance simulation results for the proposed schemes;

- Energy efficiency evaluation platform supports the evaluation of different energy efficient enhancement solutions;

- 1~2 Invention/patents, 1~2 papers will be a plus.

6 Acceptance Criteria

Design competitive energy efficiency metric and show the effectiveness to measure energy efficiency in mMTC and URLLC scenarios.

Propose energy efficient enhancement solutions with energy efficient resource management in mix scenarios and massive processing chains by jointly consider the baseband and radio frequency parts; evaluate the proposed energy efficient schemes, and ensure good energy saving gains to support 1000 times energy efficiency improvement in 5G communication networks.
7 Phased Project Plan

Phase 1 (~5 months): Research on energy efficiency metric design in 5G networks, propose energy efficiency metrics for 5G networks, especially in mMTC and URLLC and mix scenarios. Form the solution design report and the brief evaluation of the core idea.

Phase 2 (~3 months): survey the state of the art of energy efficient 5G architecture and technology with energy efficient resource management and massive processing chains in industry and academic, and identify the problems, metrics and requirements in this topic, forms technical reports.

Phase 3 (~4 months): Research on energy efficient enhancement solution design, such as energy efficient resource management, joint baseband and radio frequency processing mechanisms, energy efficient pre-coding design for massive MIMO systems. And deliver the concrete simulation results of all the solutions proposed in the project.
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Without the written consent of Huawei Technologies Co., Ltd, this document cannot be distributed except for the purpose of Huawei Innovation R&D Projects and within those who have participated in Huawei Innovation R&D Projects.
Frequency and Bandwidth Tunable Filter/Duplexer

1 Theme: Wireless Communication Technology

2 Subject: Radio Device Technology

3 Background

3.1 Characteristic of Filter

As we know from above figures, Filter takes about 20% cost of the product, 30% of the volume, which requires optimization eagerly.

3.2 Current Use of Global Frequency

Globe New Spectrum Allocation Summary-FDD
From frequency use situation of Philippine and Egypt, we know that Global Frequency has been divided fragmentary, which results in a large kinds of Filters. On the other hand, the product kind determined by Filter kind, So frequency and bandwidth fixed filter makes AAU products massive, which largely improves the research cost, and do harm to product storage and supply.

Above all, the property of Filter and use situation of Global Frequency determines Filter needs a large space of optimization, which is significant to the relief of product’s cost and volume.

4 Scope

Tunable Filter is the main research of this project, its characteristic includes but not limited as below:

1. **Frequency Tunable**: In a continuous bandwidth, such as 900M, 1.8G, 2.6G, etc, the filter center frequency can be adjusted at any or a few key frequency points according to the scene requirements.

2. **Bandwidth Tunable**: While the above frequency is adjustable, the filter bandwidth can also be adjusted according to the specific product requirements.

3. **Volume reduction**: volume is xx% lower than current mainstream macro station products.

4. **Cost reduction**: Cost reduction xx% based on current mainstream macro station products.
(5) **High power capacity:** The power capacity meets the requirements of the current mainstream macro stations and is above 40 W. If the aforementioned indicators meet the requirements, power applications can also be appropriately reduced.

5 Expected Outcome


(2) The tunable filter technology inheritance: outputs the "tunable filter/duplexer theory design specification" and "detailed design report of the key technology of the tunable filter".

6 Acceptance Criteria

Acceptance method: processing sample, physical test, output sample test report.

Acceptance criteria:

1. For samples, formulate sample specifications. Actually, the specifications listed in the specifications are the actual measurement standards, and the key technology patents shall be written.

2. Key technology inheritance: The detailed specification of key technologies is based on the standard of simulation and measurement.

7 Phased Project Plan

**Phase 1 (~3 months):**

**Work content:**

1. Tunable Filters/Duplexers Key Technology Showcases in Universities, Industry's Latest Technology Research.

2. Analysis of key specifications, alignment with mainstream products.

**Work target:**

1. Master the industry's latest technologies: new materials, new processes, new theories, regulation technologies, etc.
2. Adjustable duplexer specification formulation, aim the target products to be improved.

**Phase2 (~6 months):**

**Work content:**
Tunable Diplexer Theoretical Research, Model Design, Simulation Optimization.

**Work target:**
Get an adjustable diplexer simulation model that meets specifications.

**Phase3 (~4 months):**

**Work content:**
1. Adjustable duplexer processing, debugging, actual measurement.
3. Product conversion.

**Work target:**
1. Obtain adjustable diplexer measurement results.
2. Completion of related patents.
3. Apply to target product.
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High data rate and high-reliability/extreme-coverage uplink

MTC research

1 Theme: Wireless Communication Technology

2 Subject: Radio Transmission Technology

3 Background

Internet of Things (IoT) is revolutionizing the way we live and creates steady growth in the economy. According to the IoT paradigm, everything and everyone can be connected.

In LTE, 3GPP has standardized NB-IoT for low cost, long battery life, high coverage, and deployment of a large number of devices. For example, the coverage gain of NB-IoT is about 20dB, and the supported number of UEs in single cell is about 50000. NB-IoT operates in 200kHz carrier and has relaxed latency requirement, while the data rate of NB-IoT is also low (from X bit/s to Y kbit/s).

In NR, a range of 5G IoT use cases, such as smart grid power distribution automation, industrial manufacturing and control, intelligent transportation systems, remote control of machines, and remote surgery, are characterized by the need for reliable real-time communication with high requirements on latency, reliability, and availability. Hence, URLLC is introduced for ultra-reliable (e.g. 99.999%) and low latency (e.g. 1ms) communication. Typically a packet of URLLC transmission is small, for example 32bytes, which means the data rate of URLLC service is low.

It can be note that NB-IoT and URLLC are both focus on low data rate transmission. Currently high data rate MTC has not been deeply discussed in 3GPP standard. Due to limitation of transmit power and number of antenna ports, uplink transmission is more challenging for high data rate MTC, which should be mainly considered.

On the other hands, the number of UEs may increase in the following years, e.g., comparing with 2020, the number of UEs may be x10~x100 in 2030 based on the report
from ITU. Therefore, there will be strong requirement on MTC capacity enhancement, which is a challenge for MTC.

With the development of cities, UE’s demand for wall penetration increases. Therefore, we need to support stronger coverage under ensuring better user experience, which can cover more areas than NB-IoT. In addition, in order to support higher battery life, the transmission power of users may be further reduced, so new coverage enhancement technology is needed to ensure at least the original coverage level.

For future evolution of MTC, the following issues should be further studied:

- High data rate
- Larger number of connections
- High Reliability
- Low latency
- Extreme coverage

An important combinations of above issues needed for study is high data rate and high reliability uplink MTC which is shown as an example in TR 22.804 named Real-time CCTV service. The service requires >4 Mbit/s data rate and 99.99% reliability. The other important combinations can be larger number of connections and extreme coverage, while another combinations are not excluded.

Based on discussion above, it’s valuable to make deeply research on uplink MTC and make possible and reasonable designs for future evolution.

4 Scope

Scenarios and requirements of uplink MTC on discussed issues.
Analyze the scenarios and requirements of uplink MTC on one or some of discussed issues, also the relevant proposed designs in papers/magazines/TR, etc.

Analyze the performance of the scenarios with traditional/proposed techniques to survey what we can do now and the challenges for improvement.

**Possible technologies to ensure enhanced performance of uplink MTC on discussed issues.**

Analyze possible technologies to fulfil the requirements and propose reasonable enhanced designs. The follows techniques can be considered while others are not excluded:

- Low PAPR waveform (DFT-s-OFDM based or non-OFDM based)
- Low PAPR DMRS
- Joint Coding and Modulation
- NOMA/SCMA for capacity enhancement
- Coding design (e.g. Polar code)
- Rate-less transmission
- MIMO with large distance between antennas
- Symmetrical Mesh link
- Low cost mesh network

**Simulation platform for verification**

Develop simulation platform to analyze the performance of scenarios on discussed issues with and without enhanced designs.

**5 Expected Outcome and Deliverables**

Technical reports of uplink MTC on some of discussed issues containing current research status, relevant technologies/ solutions which has been proposed in conferences, magazines, etc.
Technical reports of uplink MTC on discussed issues with proposed designs, containing algorithms analysis, theoretical performance expectation, simulation results, etc.

Related simulation platform with source codes.

1~2 papers/patents.

6 Acceptance Criteria

The survey report should be comprehensive with deep analysis on the recognized key points on scenarios of uplink MTC on some of discussed issues.

The proposed designs should be innovative. It should be beyond existing techniques or have new features over existing techniques. Designs should fulfil the requirements or perform closed to the requirement, or the designs can extend to other scenarios and produce considerable gains.

The gain of the solutions should be well verified with solid simulations and/or theoretical analysis. The overall design and solution should capture the trend in industry, e.g., 3GPP standards, and can be implemented or extended in 5G or future network interfaces.

7 Phased Project Plan

Phase 1 (~3 months): search and review the relevant designs and current research status for uplink MTC on some of discussed issues in conferences, magazines, etc. Make simulation for these designs if needed and form technical reports.

Phase 2 (~6 months): Produce designs for uplink MTC on some of discussed issues. The designs could contain multiple technologies that provide a significant total gains. Make theoretical analysis and simulation for the designs.

Phase 3 (~3 months): Technical reports of analysis and results of designs. Produce paper/patent. Provide analysis on further possible application and enhancement of proposed algorithm, including standard impacts and product feasibility, and give subjections of the algorithm for standard and products.
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High-performance Component Technology Research on Phase Shifter Based on Pin Diode

1 Theme: Wireless Communication Technology

2 Subject: Phase shifter, Pin diode

List of Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tr>
<td>PIN</td>
<td>PIN diode</td>
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<tr>
<td>PS</td>
<td>Phase Shifter</td>
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<tr>
<td>MIMO</td>
<td>Multiple-Input Multiple-Output</td>
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</table>

3 Background

Microwave and millimeter-wave phase shifters are one of the most important structures of the antenna series that are used in communication applications. They are used to form the main beam of the electronically scanned phase array antennas and generate the appropriate phase values for the antenna elements design while providing electronic beam steering. High-performance component technology based on Pin Diode, is enabled for Massive MIMO solid miniaturized phase shifters. However, there is no suitable miniaturized phase shifter component technology in the art which can provide good power handling capacity and offer low insertion loss.

4 Scope

In this project, the major requirement is to design a 4-bit 360 degree phase shifter with step size of 22.5°. The phase shifters will be fabricated on RTduroid® 5880 lamination board with relative permittivity of 2.2. The phase shifter, with the size 27mm*54mm min, will be
designed to operate in C-band frequencies, with a return loss and average insertion loss performance of better than 15 dB and 1.5 dB. The 4-bit phase shifter will be capable of handling power of up to 20 Watts;

5 Expected Outcome and Deliverables

- Design file and simulation model
- Specimen and testing report
- One Patent

6 Acceptance Criteria

The design of 4-Bit phase shifter with the size 27mm*54mm min, should ensure low average insertion loss of at least 1.5 dB (excluding SMA connector loss), return loss better than 15 dB from 3.3 GHz to 3.8 GHz.

7 Phased Project Plan

Phase1 (~4 months): survey and select proper topologies, design and simulation, fabricate the 4-bit phase shifter, analyze and test of the phase shifter, provide the related technical report.

Phase2 (~8 months): improve the scheme of phase shifter design, fabricate the 4-bit phase shifter, provide the final technical report including the related algorithms, simulation, testing and patents.
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Intelligent Cooperative Transmission for Massive Video Surveillance in 5G Networks

1 Theme: Wireless Communication Technology

2 Subject: Radio Transmission Technology

3 Background

Traffic generated by video applications has increasingly dominated 4G mobile networks, thereby placing great strain on network capacity. As mobile network operators transition to 5G networks, they will have to contend with both the massive increase in video traffic and heightened user expectations of service levels and quality. In the face of such challenges, despite the expected substantially enlarged network bandwidth/capacity of 5G, it is by no means assured that the enlarged bandwidth will be able to keep pace with the ever-growing demands for higher quality and resource-hungry video applications.

The emergence of massive video surveillance applications is likely to fuel continued rapid growth in video traffic. It can also be expected that the higher bandwidth of 5G networks will provide the impetus for the development of new mobile video services in M2M, IoT, telemedicine, and consumer domains.

4 Scope

- Intelligent processing algorithms for massive surveillance video
  
  Research on the intelligent processing algorithms for massive surveillance video, including target classification algorithm and dynamic hierarchical algorithm, off-line and on-line algorithms.

- Cooperative transmission mechanisms in 5G NR for massive surveillance video

- Traffic model, traffic prediction algorithms, and optimization mechanisms in 5G backhual transmission network for massive surveillance video
5  Expected Outcome and Deliverables

- The state-of-the-art investigation report of massive video surveillance in 5G networks;
- Technical reports of intelligent processing algorithms of massive surveillance video;
- Technical reports of cooperative transmission mechanisms in NR for massive video surveillance;
- Technical reports of traffic model, traffic prediction algorithm, and optimization mechanisms in 5G backhaul transmission network for massive video surveillance;
- Related simulation platform with source codes and description;
- 2 papers or 1 Invention/patents;

6  Acceptance Criteria

Achieve ~10 times gain of camera connections per MHz per sector and improve the backhaul transmission efficiency by 30% or more.

7  Phased Project Plan

Phase1 (~6 months): Survey the state of the art of massive video surveillance in 5G networks in industry and academic, and identify the problems, metrics and requirements in this topic, forms investigation reports. Research on intelligent processing algorithms of real-time surveillance video, form the algorithms design report and the brief evaluation of the core idea.

Phase2 (~6 months): Research on cooperative transmission mechanisms in NR for massive surveillance video sources based on the research findings of phase1. Research on traffic model, traffic prediction algorithm, and optimization mechanisms in 5G backhaul transmission network for massive surveillance video sources. Deliver the concrete simulation results of all the solutions proposed in the project and other deliverables.
Intent-based policy architecture for wireless network

1 Theme: Wireless Communication Technology

2 Subject: Simplified Network

3 Background

Today’s commercial wireless network products has over thousands of parameters, the function of those parameters varies from radio resource management to subscriber granularity service management. Most of such parameters are enabled by manual operation including doing conflict and consistency check, fault configuration is nevertheless inevitable, so both of complexity and expense of configuring network precisely is extraordinary high.

Even those parameters are designed to be updated dynamically, yet most of them are seldom adjusted since the initial configuration due to lack of experience and confidence, the radio network is hard to achieve its best performance all the time.

Thanks to machine learning and other advanced data analysis technologies, the intelligence can also be involved into wireless network in order to reduce human interaction as well as improve the performance. Compared to the state-of-art human based network management, intent policy architecture are going to use simplified instructions, e.g. nature language style, to tell the network ‘what to do’ instead of ‘how to do’ to reduce a large scale of the manually decision and inaccuracy.

4 Scope

A survey on intent-based related architecture, the target includes, but not limited to,

- Industrial products
- Open source communities
- SDOs

Define the intent-based architecture for wireless network
The architecture design should cover both radio access network and core network, and also do not miss the coordination between each domain.

**Morphology rules and policy mapping algorithm designs**

The intent policy design should follow some special canonical form, which strongly related to wireless network service or features. Besides, highly effective and robust algorithms used for intent mapping also required.

### 5 Expected Outcome and Deliverables

- Survey report on state-of-art intent-based related architecture, including both industrial and academic projects;
- Technical report on intent-based architecture for wireless network;
- Technical report on morphology rules and policy mapping algorithm designs in detail;
- 1~2 Invention/patents;
- 1 conference paper

### 6 Acceptance Criteria

The survey report should present deeply analysis of industrial, academic and open source community projects on intent-based policy, give an overall comparison of such projects, and highlight the advantages and disadvantages of each project.

The proposed architecture clearly defines interfaces and protocols among radio network as well as core network elements, identify valuable use cases. Coordinated with proposed intent-based policy rules and mapping algorithms, the intend-base policy architecture should reduce up to 80% manually network configuration.
7 Phased Project Plan

Phase 1 (~2 months): Survey intent-based policy or network architecture from industrial products, open source communities, e.g. Open Daylight, and other SDOs projects like IETF ANIMA. Investigate the typical requirements, use cases and reference architecture of those projects, forms a report in details.

Phase 2 (~4 months): Research on defining intent-based policy architecture, specify the interfaces and protocols clearly. Deliver the architecture designing report clarify the designing discipline and advantages, in addition, one or two patents/inventions is extremely appreciated.

Phase 3 (~5 months): Research on intent rules designing and mapping algorithms, and deliver one technical report, raise typical and valuable use cases within the report.
Interscatter communication for Internet of Things

1 Theme: Wireless Communication Technology

Keywords: Internet of Everything, Interscatter, Low power

2 Background

IoT has become the most anticipated emerging technology, and the related IOT platform is also receiving intense attention. IoT technology will mature in the next 5 to 10 years. By 2020, the total number of connected devices will reach or exceed 50 billion. The Internet of Things will include many devices, including various indoor sensors and appliances, outdoor environmental monitoring and wearable devices, etc.

Sensors and wearable device will be more and more distributed to everyday life. IoT devices are distributed in all corners and usually need to ensure that they can not be replaced with batteries for at least one year (especially for sensors implanted in the human body, so replacing the battery requires surgery and safety problems); and Considering the cost and size of the sensor, the power of the sensor's built-in battery cannot be too large.

On the other hand, in order to be able to deliver the information collected by the sensors, the sensors usually need to use a wireless connection to communicate with the central node. However, the power consumption of conventional radio frequency integrated circuits is not low and they will consume battery power too quickly. Therefore, in order to further popularize IoT sensors, new ultra-low power technology need to be designed.

With the popularity of the Internet of Things, the use of reflections to transfer signals has begun to enter the sensor field. Shyam Gollakota Joshua and R. Smith, professors of computer science and engineering at the University of Washington, presented the concept of Interscatter and published the results at SIGCOMM. The Interscatter chip is a sensor implanted inside the body or an RFID-like chip that requires ultra-low power consumption. External devices (watches, Bluetooth headsets, etc.) emit RF signals (illumination signals).
The Interscatter chip modulates the reflected signal by changing the impedance of the antenna. The reflected signal from the phone receive and demodulate the information transmitted by the Interscatter chip. Throughout the entire process, the Interscatter chip does not emit RF signals. All that needs to be done is to convert the bit stream into a modulation of the antenna impedance, so the power consumption can be extremely low.

3 Scope

The target of this project is:

- Research on key technologies and implementation bottlenecks of current Interscatter communication systems.
- Design of Interscatter communication systems: including antennas, radio frequency, and baseband algorithms etc, for lower consumption and longer distance
- Develop a prototype system to demonstrate the feasibility of the technical solution and demonstrate the actual situation of technical indicators.

4 Expected Outcome and Deliverables

- The state-of-the-art investigation report of interscatter communication technologies including Antenna/RFPHY and MAC layers, existing power consumption, communication distance, usage scenarios, restrictions, etc.;
- Reduced power consumption technologies and solutions, overall communication distance improvement solutions and technologies
- One demonstration system that can demonstrate the practical advantages of power consumption and transmission distance of IoT device.
5 Acceptance Criteria

- The proposed novel Interscatter system can significantly improve communication distance and reduce power consumption of IoT;
- The demonstration system can demonstrate the practical advantages of power consumption and transmission distance of IoT device.

6 Phased Project Plan

Phase 1 (~6 months): Survey the state of interscatter communication technologies including Antenna/RF/PHY and MAC layers, existing power consumption, communication distance, usage scenarios, restrictions, etc., forms start of the art reports;

Phase 2 (6~12 months): Research and design new communication architectures and technologies, including antennas, RF, baseband, etc., to complete the communication power consumption and communication distance demonstration of the corresponding scenarios, and give an actual demonstration system.
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Irregular form antenna beam synthesis

1 Theme: Wireless Communication Technology

2 Subject: Antenna

3 Background

With the diversification and complication of the mobile communication scene, the beam pattern of the conventional base station antenna has been difficult for future communication scenarios. The special beamforming under special antenna array mode has become one of the key technologies to satisfy multiple communication scenarios.

4 Scope

Our objective is to find a fast algorithm that can achieve the shape of any beam shape, taking into account the optimization of the matrix array morphology into the optimization factor. Specific needs are as follows.

- Discuss the possibility of machine learning to solve this problem
- Basic software functions:
  1. The optimization goal supports non-valued values, for example, you can enter > some value
  2. The goal can be weighted
  3. The optimal range of array spacing and array mode can be defined
  4. The magnitude/phase of each array can be freely designed
  5. Matlab or Python (Python is preferred) can be used to achieve this issue.
  6. Each pattern of unit can be freely imported
• **Optional functions:**

  1. Automatically optimize with HFSS and other commercial software in the electromagnetic domain, not only in ideal weight calculation

  2. It is best to set up an HFSS microstrip feed model automatically.

5  **Expected Outcome and Deliverables**

• Beam synthesis software

• Source code

• Algorithm specification

• Software instruction manual

6  **Acceptance Criteria**

All deliverables pass Huawei technical review

7  **Phased Project Plan**

**begining~4 months:**

• Discuss the possibility of machine learning to solve this problem

• **Basic software functions:**

  1. The optimization goal supports non-valued values, for example, you can enter > some value

  2. The goal can be weighted

  3. The optimal range of array spacing and array mode can be defined

  4. The magnitude/phase of each array can be freely designed

4~8months :
Basic software functions:

5. Matlab or Python (Python is preferred) can be used to achieve this issue. python

6. Each pattern of unit can be freely imported

Optional functions:

1. Automatically optimize with HFSS and other commercial software in the electromagnetic domain, not only in ideal weight calculation

2. It is best to set up an HFSS microstrip feed model automatically.
Machine Learning based Radio Transmission Technology

1 Theme: Wireless Communication Technology

2 Subject: Radio Transmission Technology

Keywords: Machine Learning, Channel Modeling and Estimation, Resource Allocation

3 Background

Future wireless network is targeted at connecting 1/m² devices with Tb/s data rate and 10ns end-to-end latency. A “pure” Internet of Things (IoT) has been proposed that the convergence of eMBB, uRLLC and mMTC services is expected on a connected device. This brings significant challenges to the wireless air interfaces. For example, the network is expected to support both ultra high reliability, low latency and low energy consumption on massive number of MTC devices. Furthermore, the fast growing scenarios and applications of wireless communications makes radio propagation much more complex. A large number of energy and complexity constrained IoT devices will be connected from severe locations, such as indoor or underground. This makes wireless channels much more difficult to model.

The existing design of Wireless Air Interface including PHY and MAC layers becomes highly complex in the diverse scenarios of future pure IoT:

- Channel models are extended with too much computational complexity. When modelling for new scenarios, channel measurement must be carried out to understand new channel characteristics, which is a time-consuming task;

- The complexity of the existing channel state information (CSI) estimation methods will greatly increase with the increase of dimension of wireless channels. Frequent exchange of CSI between receivers and transmitters increases latency and control information in pure IoT scenarios;
- Grant and Grant-free multiple access technologies cannot provide massive energy and complexity constrained IoT devices with high data rate, reliability, latency requirements;
- Spectrum efficiency of current multi numerologies resource allocation technique cannot support diverse connection scenarios. Extreme flexible and intelligent air interface and resource management schemes are needed to handle different requirements.

4 Scope

The target of this project is to investigate applications of Artificial Intelligence (AI) technologies in PHY and MAC layers to deliver smart wireless interface for future pure IoT. Initial delivery resides in the following areas while other applications can be considered:

1. Channel modelling and measurement data analytics using AI technologies

   The high complexity of modelling signal propagation in diverse scenarios makes conventional assumptions and approximations unreliable. This project aims to extract wireless channel features from huge amount of existing measurement data and tackle the modelling problem in a data driven manner. By leveraging deep learning techniques to model essential channel characteristics of pure IoT scenarios, the accuracy and complexity can be balanced and the amount of measurement work can be reduced.

2. Channel estimation schemes using AI technologies

   Blind channel estimation has been proposed to deliver “open-loop” radio access for low latency and massive connection scenarios. However, it cannot guarantee high accuracy and low complexity as the dimensions of wireless channels increases. This project will investigate the use of deep reinforcement learning techniques to deliver effective prediction of wireless channels with zero or minimum CSI exchange. Furthermore, the agent is expected to intelligently identify different propagation scenarios and apply learnt estimation models without further tuning and training.

3. AI driven radio resource allocation for connectionless multiple access
Connectionless access has been widely adopted as a way of reducing latency and signaling burden for IoT. However, the reliability, data rate, energy cannot be guaranteed due to high contentions and lack of acknowledgements. In this project, we aim to use distributed online machine learning technologies on a transmitter to intelligently identify best radio resources with high channel quality, suitable TTI, subcarrier spacing, transmit power, etc. This is purely based on information gathered from receivers of past transmission, expected QoS and data type. Such approach is expected to significantly improve transmission quality with zero or few CSI measurement, ACK feedback and scheduling information exchange on IoT devices.

5 Expected Outcome and Deliverables

- The state-of-the-art investigation report of application of machine learning technologies in wireless air interface including PHY and MAC layers, existing channel modelling, estimation, transmission, multiple access and resource allocation technologies;

- Technical report with experiment results on machine learning based channel modeling technology, with wide adaptability to diverse propagation scenarios and reduced measurement complexity and workload.

- Technical report with simulation results of novel machine learning technologies on channel estimation and transmission, to improve the accuracy and minimize the amount of CSI measurement required. Automatic searching of best physical parameters including MCS, transmit power, etc.

- Technical report with simulation result on machine learning based resource allocation technology, to improve data rate, latency, reliability, energy efficiency on connectionless radio access without centralized scheduling, CSI and ACK feedback.

- System simulation or prototype demonstration of AI driven PHY and MAC technologies, with multiple dimensions performance gains and wide adaptability to complex scenarios demonstrated. The prototype can be based on USRPs and open source protocol stacks.
6 Acceptance Criteria

- The proposed novel machine learning algorithms significantly improves accuracy and reduces complexity of channel modelling and estimation, enhances adaptability to diverse propagation environment;

- Multi dimensional system performance of data rate, latency, reliability and connections are achieved with energy and computing consumption significantly reduced on IoT devices. Minimal CSI, ACK feedback and scheduling procedure is achieved.

- Full demonstration of an intelligent radio system with machine learning implemented at PHY and MAC layers. Multi dimensional performance gains should be achieve in line with numerical analysis.

- Publications of novel machine learning algorithms for wireless communications;

- Patents of implementation of machine learning in line with standards.

7 Phased Project Plan

Phase 1 (~2 months): study the application of machine learning technologies in wireless air interface including PHY and MAC layers, existing channel modelling, estimation, multiple access and resource allocation technologies, produce start of the art reports;

Phase 2 (~3 months): develop novel machine learning technologies for channel modelling in diverse propagation scenarios, leveraging accuracy and complexity. Validation on real measurement data should be conducted.

Phase 3 (~3 months): develop novel machine learning based channel estimation technology, together with adaptive modulation and coding. Integrate the AI driven physical layer technology and produce results of ultra elastic radio transmission.

Phase 3 (~3 months): develop novel machine learning technologies for connectionless multiple access and resource allocation supporting energy and computing constrained
devices. Validate system level performance of AI driven PHY and MAC layer, with multi
dimension performance gain including data rate, latency, reliability, energy efficiency, etc.
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Multi-Dimensional Matrix Multiplication Accelerator

1 Theme: Wireless Communication Technology

2 Subject: ASIP

List of Abbreviations

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<th>Description</th>
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<tr>
<td>MIMO</td>
<td>Radio Resource Management</td>
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<tr>
<td>4G</td>
<td>4th Generation mobile network</td>
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<tr>
<td>5G</td>
<td>5th Generation mobile network</td>
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<td>SoC</td>
<td>System on Chip</td>
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3 Background

Huawei and others have noted that the complexity of the 5G air interface is an order of magnitude greater than the 4G air interface. The most obvious culprit in this complexity spike is the use of MIMO and massive MIMO, which dramatically increase the front-end complexity of signal processing and also increases computation complexity of the baseband SoC. One of the most fundamental operations within these signal processing algorithms is matrix multiplication. The complexity of matrix multiplication is \(N^3\), where \(N\) is the dimension of a square matrix; the matrix data type will also increase the bandwidth of memory access, as well as the un-continuous storage/access of memory. And to support multi-RATs(4G, 5G, IoT), the base station should support multiple antennas, bandwidths configuration, which will require the Multi-Dimensional Matrix Multiplication.

So, it is a valuable research direction to investigate the low power, highly scalable Multi-Dimensional Matrix Multiplication accelerator.
4 Scope

Low power, highly scalable Multi-Dimensional Matrix Multiplication accelerator.

Power efficiency: The proposed architecture must be very power efficiently compare to the DSP, FPGA and GPU implementation.

Flexibility: The proposed architecture is general enough so as to be efficiently utilized in any dimensional matrix-matrix or matrix-vector multiplication. To be more specific, it must be flexible support MxN (M: 2,3,4⋯,32, N: 2^n⋯ 64, 128) matrix multiplication, SVD and Cholesky decomposition. We also expect the proposed architecture could be extended to support the major AI neural networks algorithms.

Latency and area: The proposed designs should also significantly reduce the latency, and the area should also be considered.

5 Expected Outcome and Deliverables

- Technical reports of the feasibility study report of proposed architecture;
- The high level design of system architecture and simulation system;
- The detail designs and benchmark result. The implementation in FPGA is high appreciated.
- Final report on the performance, power efficiency, flexibility. Suggestions on future directions and to do list.

6 Acceptance Criteria

Propose and design the low power, highly scalable Multi-Dimensional Matrix Multiplication accelerator. We can set the target as:

- Power efficiency comparison with state of the art DSP processors, GPU or FPGA, the higher is better.
The support of MxN (M: 2,3,4...,32, N: 2^n... 64, 128) matrix multiplication, SVD and Cholesky decomposition is mandatory, the support of AI algorithms is highly preferred.

7 Phased Project Plan

Phase1 (~3 months): survey the state of the art of the relate research in the matrix multiplication; the feasibility analysis and high level design;

Phase2 (~6 months): Detail design, simulation and benchmarks design; implementation, benchmark result and analysis on performance, power, latency and area.

Phase3 (~3 months): Optimization and final report. Proposal for the future research directions and to do list.
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Nanotechnology based High Frequency Communication
System Design for Small Scale Devices

1 Theme: Wireless Communication Technology

2 Subject: Radio Transmission Technology

Keywords: nanotechnology, antennas, transceivers, metasurface, nano imprint, RF

3 Background

The Internet of Nano Things (INoT) has recently attracted a lot of interest in the communication society, which is supposed to connect massive number of physical, chemical and biological micro or nano scale sensors and actuators considered with different specific targets. It is supposed to provide new applications in Body Area Networks (BAN), such as healthcare monitoring, targeted drug delivery with feedback control, biocompatible life long care, etc. Furthermore, it can serve smart cities and smart environment, such as contamination control, urban agriculture, monitoring of renewable energy infrastructure, etc.

The capabilities of micro or nano scale machines are constrained by energy, computing performance, detection and actuation range. Integrating nano sensors with nano communication is essential to connect INoT with big data and enhances the range of applications. The development of nano antennas and transceivers is necessary to enable EM communication among nano sensors. Moreover, High Frequency (HF) band (i.e. 0.1 ~ 10 THz) is suitable for nano communications because of its small scale, short range and low power. Tunable metasurface and nano imprint technique are important in producing these nano scale THz antennas and transceivers, by providing good sensitivity, conductivity, energy convergence, small scale, etc.
4 Scope

The target of this project is to investigate emerging materials, production and RF techniques for micro or nano scale HF communications. Key research areas include but not limited to:

- Nanoelectronics for sub HF flexible transistors and circuits based on metasurfaces materials, such as graphene, MoS2, black phosphorus;
- HF nano IC design, such as tunable HF filters, lenses, resonator, gunn diodes, quantum lasers, wave plate, beam steering, waveguides, spectroscopy, etc.;
- Tunable metasurfaces for low profile high gain nano antennas;
- RF transceivers design, simulation and integration for micro or nano scale, low or zero power, limited computation and energy devices;
- Implementation of energy efficient and low complexity modulation, coding and signal processing technologies on low power baseband processor;
- Integration of nano antennas and transceivers to a nano communication system;
- Nano imprint technology for cheap nanofabrication produces (optional);
- Bio compatibility of EM communication devices (optional);

The project is expected to deliver an integral design and realization of hardware for HF communication system. Potential technology breakthroughs resides in metasurface materials and nanofabrication technology for HF nanoelectronics, transceivers, antennas, basebands integrated on micro or nano scale, power, energy and computing constrained machines.

5 Expected Outcome and Deliverables

- The state-of-the-art investigation report of nanofabrication for HF communications, nano electronics, transceivers, antennas, basebands for micro or nano sensors;
• Technical reports of novel metasurface materials and nano imprint technology for different nano electronics and antennas at HF bands;

• Full small scale transceivers design, analysis through circuit simulator and realization with metasurface nano electronics for HF waves;

• Design and production and HF small scale transmitter and receiver antenna and feed, with highly effective energy concentration and detection;

• Demonstration of a point to point nano communication system.

6 Acceptance Criteria

• The proposed novel metasurface materials and nano imprint technology can effectively solve the size, flexibility, production constraints of HF nano electronics;

• The designed nano transceivers and antennas can be implemented on extreme small scale, energy and computing constrained devices;

• Full demonstration of a ultra small scale point to point HF nano communication system, including baseband, RF, antennas. It should be compatible for extreme low energy (several years standby) and computing capability devices, with ultra high propagation loss (i.e. energy absorption from environment). Long communication range and high data rate is beneficial.

• Patents and publications on novel materials and production for HF nano electronics, design of nano antennas, transceivers, low power basebands, etc.

7 Phased Project Plan

Phase 1 (~2 months): Study the state of the art of nanofabrication, metasurface materials suitable for nano electronics, design of nano antennas and transceivers, challenges of nano communications in size, energy, complexity, etc., produce technical reports.

Phase 2 (~3 months): Design novel nanotechnology for small scale HF antennas. Provide effective energy convergence on high path loss and complex propagation scenarios.
Produce the solution reports and some nano electronic devices suitable for transceiver and antenna components.

Phase 3 (~3 months): Design novel nanotechnology for small scale HF RF components. Provide high energy efficiency, low computing complexity and small scale HF transceiver.

Phase 3 (~4 months): Integrate nano transceiver and antenna for nano communications system, numerical analysis on circuit simulators, produce technical report and deliver integrated prototype.
New-Type Antenna Array Design Algorithm

1 Theme: Wireless Communication Technology

2 Subject: Massive MIMO

List of Abbreviations

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<td>MIMO</td>
<td>Massive Multiple Input Multiple Output</td>
</tr>
<tr>
<td>RF</td>
<td>Radio Frequency</td>
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<tr>
<td>3DBF</td>
<td>Three-Dimensional Beamforming</td>
</tr>
<tr>
<td>EIRP</td>
<td>Equivalent Isotropic Radiated Power</td>
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<tr>
<td>FOV</td>
<td>Field-of-View</td>
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3 Background

Massive MIMO is considered as one of the promising techniques for 5G communication from the perspective of system capacity. It can allow for orders of magnitude improvement in spectral and energy efficiency by using a large-scale antenna array. However, with a very large number of antennas, the number of RF chains is also huge, leading to unaffordable hardware cost and power consumption in practice, especially in millimeter-wave massive MIMO systems.

In view of this, massive MIMO antenna array with reduced number of antennas/RF chains while maintaining performance, which can reduce the hardware cost and power consumption, could be an intriguing prospect for 5G-oriented base stations. Moreover, from
the perspective antenna array design, the mutual coupling effects is also one of important factors affecting the 3DBF performance.

Therefore, researching a new and efficient array design algorithm for designing an optimal massive MIMO antenna array with least number of antennas and acceptable radiation performance will be valuable and meaningful for 5G-oriented base stations.

4 Scope

A new efficient antenna array design algorithm

The proposed algorithm should be able to efficiently design a desired antenna array, and compared with a half-wavelength spaced antenna array which having the same aperture, the designed antenna array have to meet the requirements of a minimum 30% reduction in the number of antenna elements/RF chains and a maximum 10% loss in EIRP performance as well as a maximum -10dB peak side lobe level when its 3D beam is scanned within the scan FOV. Moreover, the algorithm should be made more general not limited to a specific example.

Scan FOV: [-60°, 60°] of horizontal plane and [-15°, 15°] of vertical plane

Whole FOV: [-90°, 90°] of horizontal plane and [-90°, 90°] of vertical plane

A mathematic analytic model for characterizing the mutual coupling effects

A mathematic analytic model for characterizing the mutual coupling effect between patch elements should be integrated in the proposed antenna array algorithm, and the resulting 3DBF performances of a designed patch antenna array should have a good agreement (at least 95%) with those obtained from the full-wave electromagnetic simulation software. Moreover, the proposed mathematic analytic model scheme should has a certain generality not limited to a specific patch antenna.

3DBF performances: array gain and radiation pattern including main lobe, half-power beam width, side lobes, and null locations.
5 Expected Outcome and Deliverables

- Technical reports of the state-of-the-art array design methods and the proposed array design algorithm;
- Technical report of the proposed mathematic analytic model scheme;
- Related simulation platform with source codes and description
- 1~2 Invention/patents;

6 Acceptance Criteria

1) Required technical materials (i.e., reports, source codes, and patents) should be completed.

2) Changing the total number of antenna elements/RF chains, the resulting antenna arrays should meet all the requirements as detailed in subsection 4 (Scope).

7 Phased Project Plan

Phase 1 (~6 months): complete the survey of the state-of-the-art array design methods, propose preliminary array design algorithm and mathematic analytic model scheme, and provide the related technical reports.

Phase 2 (~6 months): complete the simulation platform with source codes and description, provide several simulation examples, and provide the final technical reports and patent(s).
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Without the written consent of Huawei Technologies Co., Ltd, this document cannot be distributed except for the purpose of Huawei Innovation R&D Projects and within those who have participated in Huawei Innovation R&D Projects.
NoC for memory transactions

1 Theme: Wireless Communication Technology

2 Subject: Chip architecture

List of Abbreviations

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<tbody>
<tr>
<td>NoC</td>
<td>Network on Chip</td>
</tr>
<tr>
<td>LR</td>
<td>Latency Rate</td>
</tr>
<tr>
<td>RTL</td>
<td>Register Transfer Level</td>
</tr>
<tr>
<td>ID</td>
<td>Identifier</td>
</tr>
<tr>
<td>AXI</td>
<td>Advanced eXtensible Interface</td>
</tr>
</tbody>
</table>

3 Background

3.1 NoCs have been a topic in research for many years and several products use NoCs. Still there are remaining challenges. NoCs can be used in different ways.

4 Scope

4.1 In this project the focus is on NoCs for memory transactions. The nodes in the NoC are masters and/or slaves. The transactions are requests and responses for reading and writing data. Requests are sent from masters to slaves and responses the in the other direction.

It must be taken into account that:

1. Masters can only handle a limited number of outstanding transactions.

2. There are ordering constraints, such as transactions with the same ID must be executed in order and responses must be returned in order.
3. Some transactions are more urgent than others. The transaction ID may be used to determine the service for a group of transactions. LR service is desirable.

4. Masters typically use an AXI port to interact with the slaves. The AXI4 protocol must be supported.

5. Topology must be 2D mesh for easy floorplanning.

6. HW cache coherency is not required, but may be supported.

5  Expected Outcome and Deliverables

5.1 A NoC design proposal based on state of the art research results.

5.2 RTL code for NoC bridges and NoC switches.

Detailed requirements specification.

Evaluation report including benchmark specification.

6  Acceptance Criteria

6.1 High quality reports

7  Phased Project Plan

Phase1 (~3 months):
Survey existing NoC proposals.
Finalize requirement specification.

Phase2 (~6 months):
Design internal protocols, links, switches, and bridges.
Prototype RTL code.

Phase3 (~3 months):
Evaluate.
Write reports.
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Optical interconnection and routing for optical beam forming

1 Theme: Wireless Communication Technology

2 Subject: Optical Architectures

List of Abbreviations

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<tr>
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<tbody>
<tr>
<td>PIC</td>
<td>Photonic Integrated Circuit</td>
</tr>
<tr>
<td>BTS</td>
<td>Base Transceiver Station</td>
</tr>
<tr>
<td>AWG</td>
<td>Array Waveguide Grating</td>
</tr>
</tbody>
</table>

3 Background

Future BTS architecture will require the need to switch, and process large amounts of optical signals. Also future BTS Antennas will need to support large bandwidths and large channels separations (28GHz, 39GHz, and 60GHz). Optical Technologies have the ability to increase the flexibility of the BTS architecture to support these extended requirements.

Photonic Integrated Circuits (PICs) are becoming the primary technique to combine and switch optical signals and in the future will begin to replace some of the functions currently used in conventional RFIC circuits.

Optical beamforming through the uses of PICs and coherent optical mixing has the potential to provide ultra-wideband radio beamforming.
4 Scope

This project will investigate the feasibility of an optical beam formed system using photonic techniques. The project will evaluate the key components required to enable the optical BTS architecture, including lasers, modulators, phase shifters, AWGs, switches, and optical receivers.

5 Expected Outcome and Deliverables

1) Recommendation on suitable optical architectures.

2) A report on the uses of optical techniques within the BTS architecture

6 Acceptance Criteria

Accepted Optical Architecture

7 Phased Project Plan

Phase1 (~3 months): PIC Component Analysis

Phase2 (~6 months): PIC Architecture Design

Phase3 (~3 months): Report and Simulations
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Optical signal processing based adaptive RF beamforming technology

1 Theme: Wireless Communication Technology

2 Subject: Radio Transmission Technology

3 Background

Massive MIMO(m-MIMO) was accepted as a 5G technology to improve the spectrum efficiency. But current m-MIMO implementation based on one transceiver per channel generate the difficulty to product and solution, Power consumption/Size of radio unit/Heavy equipment, Cost...

Optical beamforming technology was investigated in radar system. Fig1 shows beamformer in transmitter direction. The RF signal is converted to optical signal first, then the optical signal is handled in optical domain, the processed signal is then send to the antenna element. The PD in antenna element converts the optical signal to RF signal. The system is a really RF beamformer. There is only one DAC in the system. The RF beam is decided by the control signal on SLM.

Fig1. Example of optical beamformer

Source: Borja Vidal, “Optical beamformer for large microwave antenna arrays”

DDMZM: dual-drive Mach-Zehnder modulator.
DGD: differential group delay.
ODL: optical delay line.
PD: photodetector.
RF: radio frequency.
SLM: spatial light modulator.

At receiver direction, the beamforming can be also done optical domain. The RF signal is converted to optical signal at the antenna element, then the optical signal is handled in optical domain, the processed signal is then send receiver(O/E, down-converter, ADC,..). There is only one ADC in the system. The RF beam is decided by the control signal to optical components.

It has many advantages over electrical beamformers, such as a light weight, low loss, and large bandwidth. But for m-MIMO, the research result is few.

4 Scope

We wish the investigator can investigate the latest progress on optical beamformer, including the components/subsystem/algorithm, and the idea of using optical beamformer to m-MIMO system. Proposal on the research direction combining the m-MIMO and Optical beamformer are also welcome.

The following research topics are considered:

- Programmable optical signal processing subsystem on sub-6GHz and mmWave. The number of antenna element will be hundreds.
- The feasibility of multi-user linear precoding based on optical processing.
- The feasibility of multi-user detection based on optical processing.
5 Expected Outcome and Deliverables

- The state-of-the-art investigation report of optical beamformer and requirements used in wireless transmission;
- Technical reports of optical beamformer in m-MIMO and the performance simulation of the schemes;
- 1~2 Invention/patents;

6 Acceptance Criteria

The report will reviewed by Huawei experts. The report should cover the latest progress based on public publications. The mathematic model should be reasonable. The simulation result should repeatable.

7 Phased Project Plan

Phase1 (~3 months): survey the state of the art of optical beamformer for transmitter and receiver;

Phase2 (~6 months): Research on optical beamformer based m-MIMO concept. Form the solution design report and the brief evaluation of the core idea.

Phase3 (~3 months): Research on optical beamformer optimization and the algorithm framework. And deliver the concrete simulation results of all the solutions proposed in the project.
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PPM level frequency generation technology with photonic mixing

1 Theme: Wireless Communication Technology

2 Subject: High Frequency

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<tbody>
<tr>
<td>ppm</td>
<td>parts per million</td>
</tr>
<tr>
<td>RoF</td>
<td>radio over fiber</td>
</tr>
</tbody>
</table>

3 Background

- Typical mmWave/THz circuit transceiver is built in electrical domain, but due to high frequency, all electrical domain mmWave/THz generation is complex and low efficiency. Photonic mixing is an important alternative.

- Photonic mixing technology gets the difference signal between two optical signal, which is simple at the system structure.

- However, the spectrum regulation typical restrict the stability of wireless signal to ppm level, which cannot easily be solve by simple two free run lasers

- New photonic mixing architecture with frequency stability function would be an important preparation for RoF usage.

4 Scope

Heterodyne Photonic mixing Frequency stabilization technology Survey
Survey about heterodyne photonic mixing compatible frequency stabilization technology, propose basic idea with balance between simple/compact and semiconductor technology compatibility, if external clock referred, that will be preferred.

**Detailed Heterodyne Photonic mixing Frequency stabilization technology**

- Investigate detailed technology solution, provide full methodology, including topology, simulation for expected performance, key components or material analysis, etc;

5 Expected Outcome and Deliverables

- Technical reports of Heterodyne Photonic mixing Frequency stabilization technology Survey;
- Technical report or simulation for detailed Heterodyne Photonic mixing Frequency stabilization technology analysis;

6 Acceptance Criteria

Technology survey reports covers almost present study, related technique aspects are covered, well logic organized;

Proposed solution is clear, match with simple/compact and semiconductor technology compatibility;

7 Phased Project Plan

Phase1 (~3 months): Technical reports of Heterodyne Photonic mixing Frequency stabilization technology Survey.

- Phase2 (~9 months): Investigate detailed technology solution, provide full methodology, including topology, simulation for expected performance, key components or material analysis, etc;
Research on Active Impedance Immune Antenna-in-Package Phased Array

1 Theme: Wireless Communication Technology

2 Subject: Phased Array Communication System

List of Abbreviations

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<th>Description</th>
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<tbody>
<tr>
<td>AIP</td>
<td>Antenna in Package</td>
</tr>
<tr>
<td>AI</td>
<td>Active Impedance</td>
</tr>
<tr>
<td>AIC</td>
<td>Active Impedance Characterization</td>
</tr>
<tr>
<td>AII</td>
<td>Active Impedance Immune</td>
</tr>
<tr>
<td>ARL</td>
<td>Active Return Loss</td>
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</table>

3 Background

AIP is the most promising technology for the next generation high frequency phased array communication system. Because of the inherent non-isolator architecture, it is very difficult to improve the output power of AIP system given that most high efficiency PAs are very sensitive to the load and the active impedance (AI) of AIP varies vastly on different scanning angles. Phased array engineers have good understanding on the reason of AI but few had reported on how to measure the ARL and make an AIP phased array with AI Immune (AII) characteristics. So, it is a valuable research direction to investigate the way for the characterization of AI (AIC) and furthermore performance optimization of AIP phased array system, so that the high efficiency PAs could be enabled in AIP phased array,
which is crucial for the business success of the next generation high frequency communication.

4 Scope

Measurement and characterization on the Active Impedance of AIP Phased Array

Investigate on the AIC scenarios in an AIP phased array;

Investigate on the architecture with AIC for AIP chips and the feasibility for prototype and mass production;

Active Impedance Immune AIP Architecture

Investigate on the method that can mitigate the AI problem, e.g. tunable matching network;

Investigate on the architecture with AII characteristics for AIP chips and the feasibility for prototype and mass production.

5 Expected Outcome and Deliverables

- Technical reports on the measurement and characterization scenarios of AI;
- Technical reports on the AII scenarios;
- Related simulation platform with source codes, description and simulation report
- 1~2 Invention/patents;

6 Acceptance Criteria

Deliver feasible scenarios for the AIC with accuracy better than +/-2dB and feasible architecture with AII characteristics for AIP chips;

7 Phased Project Plan

Phase1 (~3 months): Literature survey on the AI problem of phased array and give proposals for solutions on the AIC/AII.
Phase 2 (~6 months): Verify the proposals by means of analysis, simulation, measurement etc., deliver verification reports, simulation files and verification conclusions.

Phase 3 (~3 months): Research on the chip architecture with AIC/All characteristics and feasibility for prototype and mass production.
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Research on Base Station Heterogeneous Computing

1 Theme: Wireless Communication Technology

2 Subject: Heterogeneous Computing

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<tr>
<td>NR</td>
<td>New RAT</td>
</tr>
<tr>
<td>RLF</td>
<td>Radio Link Failure</td>
</tr>
<tr>
<td>RRM</td>
<td>Radio Resource Management</td>
</tr>
<tr>
<td>BRS</td>
<td>Beam Reference Signal</td>
</tr>
</tbody>
</table>

3 Background

With the introduction of NR technology, the coexistence of 4G and 5G, various low-latency, high-throughput applications and technology co-existence demands have brought many challenges to the system's processing capability, resource efficiency, and energy efficiency ratio.

To cope with the challenges, it is necessary to consider how to build an efficient and high-performance execution platform. While exerting its hardware capabilities, it can effectively support applications to respond quickly to new business demands..

4 Scope

Computation Unit on Heterogeneous Computing
Investigate how to build a unified, high-performance, energy-efficient, and easy-to-use business platform to address the trend toward converged heterogeneous computation architectures.

**Memory mechanisms on Heterogeneous Computing**

Investigate memory management architecture and key algorithms for heterogeneous computing systems, support mixed management of SRAM, DDR, distributed memory, etc.

Investigate the priority strategy on memory usage to determine the performance gains obtained by the service to satisfy diversity, different time delay request of 5G service.

Investigate cache replacement algorithms for performance and DDR bandwidth. Cache-miss has a great impact on application performance, especially in a limited DDR bandwidth environment, so a good cache algorithms or architecture should be researched to improve the overall system performance.

5  **Expected Outcome and Deliverables**

- Technical reports of industry common memory model and heterogeneous scheduling algorithm
- Technical reports of optimized memory model and heterogeneous scheduling algorithm for base station
- Related simulation platform with source codes and description
- 1~2 Invention/patents;

6  **Acceptance Criteria**

Design competitive platform of heterogeneous computing system for base station;
7 Phased Project Plan

Phase 1 (~6 months): survey the state of the industry memory model and heterogeneous scheduling algorithm

Phase 2 (~6 months): research on optimized memory model and heterogeneous scheduling algorithm for base station
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Research on Broadband Dual-Polarized mm-wave Patch Antenna Array

1 Theme: Wireless Communication Technology

2 Subject: 5G Millimeter-Wave Antenna Array

List of Abbreviations

| PA | Power Amplifier |

3 Background

Patch antenna arrays are of great importance in the applications of 5G mm-wave communication. Main 5G frequency bands including GP30G, GP40G, V-Band, as shown in Figure. 1, require the antennas to operate with fractional bandwidth (FBW) from at least 14.6% up to 19.6% or even more. Nevertheless, typical FBW of currently widely used patch antenna is only about 10%, which leads to the failure of meeting the full-band coverage requirement, and the unsatisfactory performance of platform realization.

In addition, the success of employing polarization diversity in 4G to enhance the channel capacity also urges dual polarization to be achieved in 5G mm-wave communications. Due to the limited space for accommodating antennas, appropriate design and arrangement of
patch arrays and corresponding feed lines for both polarizations, with satisfactory performance maintained, are considerably challenging and worth of investigating.

Moreover, mutual coupling between array elements remains a concerned problem, which can seriously deteriorate the array performances to different degrees. On one hand, serious mismatch of active load impedance of the power amplifier caused by mutual couplings, can lead to an unacceptably remarkable reduction of the total radiated power.

Therefore, in order to meet the increasing demand of 5G mm-wave communication, and construct substantially high-level competence, it is very important to investigate innovative dual polarized patch arrays with characteristics of broadband and greatly reduced mutual couplings.

4 Scope

Investigate broadband dual polarized patch antenna arrays with the following specifications:

1) 24.25~29.5GHz, VSWR≤1.5;
2) ±45° dual polarization;
3) Total efficiency of antenna array ≥ 75%;
4) Array size ≥ 5×5;
5) Co-polarized element isolation ≥ 21dB, Cross-polarized element isolation ≥ 25dB
6) Scan scope: Azimuth ±60°, Elevation ±15°;
7) Antenna profile≤1.2mm.

5 Expected Outcome and Deliverables

The realization of broadband dual polarized patch arrays and innovative techniques of reducing mutual couplings, satisfying the specifications listed in Section 4. Specifically:

- Technical reports on the realization principle and design of mm-wave broadband dual polarized patch arrays, including but not limited to the simulation model and the simulated results;
Technical reports on the principle and methodology of reducing mutual couplings in mm-wave patch arrays, including but not limited to the simulation model and the simulated results.

6 Acceptance Criteria

- The simulated results of the delivered simulation model should satisfy the specifications listed in Section 4;
- The technical reports should provide detailed analysis and design procedures of the simulation model, with specific design method described.

7 Phased Project Plan

Phase1 (~2 months): Complete the negotiation, confirmation and signing of the contract.
Phase2 (~6 months): Implement the specification analysis, feasibility analysis, and convergence of candidate solutions.
Phase3 (~4 months): Research in detail on the design and simulation of the broadband dual polarized patch antenna array with enhanced isolation. To accomplish the project, provide the deliverables with specifications satisfied, and deliver the required reports.
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Research on design techniques of high-efficiency digital PA

1 Theme: Wireless Communication Technology
2 Subject: High Frequency

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<tbody>
<tr>
<td>RF</td>
<td>Radio frequency</td>
</tr>
<tr>
<td>DPA</td>
<td>Digital Power Amplifier</td>
</tr>
<tr>
<td>DAC</td>
<td>Digital-to-analog converter</td>
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</table>

3 Background

The RF power amplifier is a key module of the base station and the terminal system, whose efficiency directly affects the performance of the system. With the ever-increasing requirements for high-data rates in multiple communication standards, RF PA with high efficiency are highly demanded. Recently, digital PAs have drawn much attention due to their advantages, especially in scaled CMOS technologies, such as high efficiency with fairly linear RF-DAC output, full compatibility with digital baseband, and seamless on-chip digital calibration. The ever-growing demands towards high efficiency feature together with the repaid progress in new semiconductor process materials and the advantages of high-performance digital processing circuits have been fueling research on new architecture of DPAs, which have enormous potential to improve the efficiency further as well as overcome the bottleneck of efficiency improvement of the traditional analogy PA.

So, this project will focus on investigating the architectures and design schemes of DPA to ensure high efficiency performance requirements in the wireless transmitter system.
4 Scope

High-efficiency DPA architecture and design scheme

Investigate a new high-efficiency DPA architecture and design scheme, includes: the construction principle of the DPA architecture, the methods of amplification, efficiency improvement and modulation, the configuration and control algorithms, the Constraining factors of efficiency improvement in the implementation, and so on;

5 Expected Outcome and Deliverables

- Technical survey reports of existing high-efficiency digital PA solutions and;
- Technical reports of developed DPA circuit design scheme;
- Related simulation platform with the high-efficiency DPA;

6 Acceptance Criteria

- The comprehensive and state-of-the-art survey reports of existing high-efficiency DPA and DPA-based transmitter solutions in literature and comparison of the advantages and disadvantages of different solutions;
- The complete technical analysis report and simulation verification results, including clear theoretical and data results to prove the research results and performance of the technical direction, and detailed analyses and descriptions about the construction principle of the DPA architecture, the methods of amplification, efficiency improvement and modulation, the configuration and control algorithms, and the Constraining factors of efficiency improvement in the implementation;
7 Phased Project Plan

Phase 1 (~4 months): survey the state of the art and the existing high-efficiency DPA and DPA-based transmitter solutions in literature, compare the advantages and disadvantages of different solutions, and provide the related technical reports.

Phase 2 (~9 months): have a detailed design and simulation evaluation for the high-efficiency DPA, and provide the related design technical report, simulation platform.
Research on Low-profile High-gain Omnidirectional Ceiling Integrated Antenna Technology

1 Theme: Wireless Communication Technology

2 Subject: Integrated Antenna

List of Abbreviations

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<tr>
<td>ARG</td>
<td>Average Realized Gain</td>
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<tr>
<td>DAS</td>
<td>Distributed Antenna System</td>
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</table>

3 Background

With the increase of data traffic especially in indoor ceiling scenario, better communication coverage is becoming very urgent. Antenna performance plays an important role in better indoor coverage, which requires omnidirectional patterns aiming at targets instead of interference. That is to say, the patterns are expected as bagel-shaped. ARG of antenna from theta 45 to 80 degree is of great concern.

To improve indoor coverage, DAS technology with above high-gain omnidirectional patterns may be used in some scenarios. DAS antenna with height more than 100mm has a big volume more than 2 liters, which is not suitable for the requirements of miniaturization and integration in small cell applications.

As a result, it is valuable to research wideband omnidirectional ceiling antenna integrated into small cells with lower profile and desired high-gain patterns for better indoor coverage.
4 Scope

ARG improvement mechanisms

Investigate the vertical beam tilting and ARG improvement mechanisms, including finding novel composite structures to adjust the radiation beam along the desired direction, achieving high-efficiency feeding and ultra-wideband impedance matching.

Low-profile antenna mechanisms

Investigate the antenna miniaturization mechanisms, including how to decrease the height and aperture area of antenna, ensuring high-gain omnidirectional patterns and wideband performance.

5 Expected Outcome and Deliverables

- Technical reports of ARG improvement mechanisms;
- Technical reports of low-profile antenna mechanisms;
- Related antenna prototype with simulated and measured results;
- 1~2 Invention/patents;

6 Acceptance Criteria

Design low-profile antenna with height of 20mm and ensure good performance at least not worse than DAS.

7 Phased Project Plan

Phase1 (~3 months): survey the ARG improvement and antenna miniaturization technology, analyze and provide the related technical report.

Phase2 (~6 months): research on schemes of low-profile high-gain antenna design and simulation, and provide the related technical report.
Phase 3 (~3 months): research and provide related prototype integrated into small cells, measured results and patents.
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Research on signal and noise modeling of ultra-high speed low-precision quantizer

1 Theme: Wireless Communication Technology

2 Subject: High Frequency

List of Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADC</td>
<td>Analog-digital converter</td>
</tr>
<tr>
<td>S/H</td>
<td>sample/hold</td>
</tr>
<tr>
<td>RF</td>
<td>Radio frequency</td>
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</table>

3 Background

In the future, communication systems are expected to provide high data rates up to hundreds Gbps. To achieve this goal, extremely large bandwidths are needed. When the received signals of high-rate large-bandwidth systems are processed digitally, analog-to-digital converter (ADC) becomes a key bottleneck. Since the power consumption of ADC is proportional to $2^b$, where $b$ is the bit width of ADC, high-speed high-resolution ADC is power-hungry and costly. Therefore, low-resolution ADC has attracted significant attention of late, both in view of receiver design and in view of information-theoretic aspects.

The quantization noise in a low-precision ADC has a significant impact on the performance of wireless communication system. Traditionally, the noise is following Gaussian distribution. However, due to the ADC is a nonlinear module, this model is not accurate for other kinds of noises, such as multiplicative noise. Hence, it is desired to build a more accurate signal and noise model for the ultra-high speed low-precision quantizer.
So, this project will focus on investigating the ultra-high speed sampling and quantification scheme as well as signal and noise modeling for the ultra-high speed low-precision quantizer.

4 Scope

Ultra-high speed sampling and quantification scheme

Investigate the ultra-high speed sampling and quantification architecture and scheme for the ultra-high speed low-precision quantizer.

Signal and noise modeling of ultra-high speed low-precision quantizer

Investigate the signal and noise modeling of ultra-high speed low-precision quantizer: including the modeling methods, statistical model, and so on;

Model demonstration

Investigate the model demonstration methods based on the proposed model of the ultra-high speed low-precision quantizer and have a model verification.

5 Expected Outcome and Deliverables

- Technical survey reports of existing architecture schemes of ultra-high speed sampling and quantification and signal and noise modeling methods of ultra-high speed low-precision quantizer;
- Technical reports of the signal and noise modeling of ultra-high speed low-precision quantizer;
- Related simulation platform of the signal and noise model of ultra-high speed low-precision quantizer;
6 Acceptance Criteria

- The technical survey reports are comprehensive and have a clear technical roadmap for the future technique evolution of the ultra-high speed sampling and quantification architecture;

- The technical analysis report and simulation verification results are complete, including clear theoretical and data results to prove the research results and performance of the technical direction;

7 Phased Project Plan

Phase 1 (~6 months): survey the state of the art and the existing architecture schemes of ultra-high speed sampling and quantification and signal and noise modeling methods of ultra-high speed low-precision quantizer in literature, and compare the advantages and disadvantages of different solutions, and provide the related technical reports.

Phase 2 (~6 months): have a detailed modeling and simulation evaluation for the signal and noise model, and provide the related design technical report and simulation platform.
Research on the IPv6 Algorithm of the Base Station

1 Theme: Wireless Communication Technology

2 Subject: Base station transmission

List of Abbreviations

<table>
<thead>
<tr>
<th>ACL</th>
<th>Access Control List</th>
</tr>
</thead>
</table>

3 Background

Huawei base station needs to support IPv6. The base station has the following features: Limited memory, high forwarding performance, dynamic configuration, and large specifications. To meet IPv6 network requirements, we need to study the most cost-effective IPv6 routing and ACL search algorithms in advance to improve the competitiveness of IPv6.

4 Scope

Research on IPv6 Routing Search Algorithm

Function Description:

- The matching keyword is the IPv6 destination address.
- The same IPv6 destination address needs to match the entry with the longest mask.
- Supports dynamic configuration, including adding, deleting, and updating.

The route search algorithm needs to take the memory usage, configuration efficiency, and search efficiency of the algorithm as the first priority.

Research on IPv6 ACL Search Algorithm
Process flow chart

Function description:

- Matching keyword contains the 6-tuple combination (source IPv6 address, destination IPv6 address, DSCP, protocol, source port and destination port). Any field can be set to don't care.

- Supports mask matching for source IPv6 addresses and destination IPv6 addresses. Supports accurate DSCP matching. The range of the protocol number, source port number and destination port number can be matched.

- A group of ACL rule sets contains multiple ACL Rule with specified priorities. Matching is performed in descending order of priority. The ACL Rule that matches all bit fields is considered as the matching result.

- Supports dynamic configuration, including add, delete and update.

The ACL search algorithm needs to take the memory usage, configuration efficiency, and search efficiency of the algorithm as the first priority.
5 **Expected Outcome and Deliverables**

- IPv6 Routing and ACL Search Algorithm Performance Verification Report (Including Benchmark Data)
- IPv6 Routing and ACL Search Algorithm Description and Implementation Code
- Invention/Patent (if any)

6 **Acceptance Criteria**

Requirements: These two algorithms are independent to any hardware platform. Any Non-C or Non-C++ code for performance optimization is not expected. The design of these two algorithms will probably be implemented by hardware accelerators.

- The max number of ACL rules is 64K
- The max number of IPv6 Route is 64K
- Any Adding/deleting/updating of ACL rule or IPv6 route do not slow down the ACL and IPv6 searching process.
- High searching efficiency. For example, with ACL rule number of 1K, the time for any single search does not exceed ~150Cycles.
- The searching efficiency of each algorithm can vary when the number of ACL rule or IPv6 route varies. However, the difference between the best performance and the worst performance need to be controlled with 20% for ACL algorithm and 3% for IPv6 route algorithm.
- Low memory usage. For example, with ACL rule number of 1K, the memory usage does not exceed 20 MB.
- Output the benchmark baseline for each algorithm, such as memory usage (MB), search efficiency (Cycle), and configuration efficiency (Cycle).
7 Phased Project Plan

Phase1 (~6 months): Research the IPv6 route search algorithm and provide the performance verification report, algorithm description, code, and patent that meet the acceptance criteria (if any).

Phase2 (~6 months): Research the IPv6 ACL search algorithm and provide the performance verification report, algorithm description, code, and patent that meet the acceptance criteria (if any).
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ROF linear problem analysis and solution

1 Theme: Wireless Communication Technology

2 Subject: ROF Linear Problem

3 Background

Optical wireless communication radio-over-fiber (RoF) technology is a new wireless access technology combining high-speed optical fiber communication and wireless communication. Simply speaking, the microwave is modulated to the laser at the central station. After that, the modulated light wave is transmitted through the complex fiber link. After arriving at the base station, the photoelectric conversion will demodulate the microwave signal and transmit it to the user through the antenna. Optical fiber transmission has been applied more and more widely because of its high bandwidth, large capacity and low loss, especially for long-distance and ultra long distance transmission.

Because analog optical fiber transmission bandwidth, huge carrier transmission in the 5G era is more suitable for ultra wideband M-MIMO, with the rapid development of 5G, high and low frequency are recognized as the main band of 5G, and the MassiveMIMO technology was applied on 5G, multi-channel, total station access, high frequency hybrid network has become the main demand.

Therefore, solving the ROF linear problem is a valuable research direction in the ROF application.

4 Scope

Prepass architecture based on wireless communication system

The RoF system uses optical fiber as the transmission link between the base station (BS) and the central station (CS), and uses the optical carrier to transmit the radio frequency signal directly. Fiber only plays the role of transport, exchange, control and signal regeneration are concentrated in the central station, the base station only to achieve photoelectric conversion, so that the complex can be expensive equipment to the central site, let more remote base station sharing these devices, reduce the power consumption of the base station and cost ;

With the increase of signal bandwidth, transmission frequency and transmission distance increasing, the nonlinear problem of ROF system restricts the use scenario of ROF. By
quantifying the nonlinear cause of ROF, it optimizes the nonlinearity of ROF by algorithm, so as to achieve the requirement of system specification.

5 Expected Outcome and Deliverables

- ROF nonlinear quantitative analysis report;
- ROF nonlinear solution report;
- Source code and description of the related algorithms

6 Acceptance Criteria

- 1, ROF prepass system nonlinear problem solution:
  Through modeling and simulation, the transmission distance is 20Km, the modulation signal bandwidth is 800M, the carrier frequency is in the 5GHz, and the ACLR - 45dBc.
- 2 related reports: detailed description of the ROF system nonlinear causes and solutions;
- 3 code: matlab code that can reproduce the result of the algorithm simulation

7 Phased Project Plan

Phase1 (~6 months): Completion of system construction and algorithm model establishment and preliminary analysis of the quantitative analysis of the effects of ROF and fiber on Performance.

Phase2 (~12 months): Complete the algorithm optimization and meet the performance specification requirements.
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Signal Processing Technology Based on Low Precision Quantization

1 Theme: Wireless Communication Technology

2 Subject: Architecture and Resource Management

List of Abbreviations

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<th>Description</th>
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<tbody>
<tr>
<td>ADC</td>
<td>Analog-to-Digital Conversion</td>
</tr>
<tr>
<td>OFDM</td>
<td>Orthogonal Frequency Division Multiplexing</td>
</tr>
<tr>
<td>MIMO</td>
<td>Multiple Input Multiple Output</td>
</tr>
<tr>
<td>(I)FFT</td>
<td>(Inverse) Fast Fourier Transformation</td>
</tr>
</tbody>
</table>

3 Background

Future communication systems tend to be more bandwidth and higher frequency. Due to the unacceptable cost and high power consumption, high-precision (8-16 bits) analog-to-digital conversion (ADC) with ultra-high speed and high precision becomes the limiting factor in modern transceiver architectures. Available ultra-high speed ADCs are normally 4-6 bit quantization, which brings high performance loss in the practical communication systems. On the other hand, from information theory perspective, the capacity loss is not that large like practical use. Therefore, it is valuable to research towards the new architecture and signal processing algorithms based on low precision quantization.
4 Scope

Information theory under the condition of low precision quantization

Analyze theoretical capacity loss or limitation due to low precision, including but not limited to high-order modulation, OFDM, MIMO/beam forming. The theory analysis can give insight to the practical transceiver/receiver architecture design.

Signal Processing Algorithms based on low precision quantization

Explore signal processing algorithms based on low precision such as synchronization, beamforming, MIMO detection, modulation/demodulation, FFT/IFFT, channel estimation, coding/decoding. The signal processing algorithms can boost the performance of the practical communication system using low precision quantization and thus reduce the gap to the information theory.

5 Expected Outcome and Deliverables

- Technical reports on Information theory under the condition of low precision quantization;
- Technical reports on Signal Processing Algorithms based on low precision quantization;
- Related simulation platform with source codes and description
- 1~2 innovation ideas;

6 Acceptance Criteria

- Propose signal processing algorithms based on low precision quantization and boost at least overall 10% performance gain compared with conventional signal processing algorithms;
- The innovation ideas are documented in a way suitable for development of IPR, and reviewed and passed by Huawei CRI technology expert committee.
7 Phased Project Plan

Phase 1 (~3 months): survey the state of the art of Information theory under the condition of low precision quantization, and provide the related technical report.

Phase 2 (~6 months): explore signal processing algorithms based on low precision such as synchronization, beamforming, MIMO detection, modulation/demodulation, FFT/IFFT, channel estimation, coding/decoding, and provide the related technical report with simulation results.

Phase 3 (~3 months):

Propose novel signal processing algorithms based on low precision quantization, and provide innovations.
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Single line microwave transmission line

1 Theme: Wireless Communication Technology

2 Subject: High Frequency

List of Abbreviations

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<th>Description</th>
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<tbody>
<tr>
<td>mmWave</td>
<td>millimeter wave</td>
</tr>
<tr>
<td>SPPs</td>
<td>surface plasmon polaritons</td>
</tr>
</tbody>
</table>

3 Background

- Presently more and more on board or chip inter-connections are needed. Using classical two line transmission line is every common in industry. But it takes more layers and also cause cross talk with common ground. On other hand, waveguide is transformed to SIW for easy usage, but still hard to use in high integration solution.

- Single transmission line with low loss at mmWave is promising, some study such as SPPs is on-going, further study is needed.

4 Scope

Single line transmission line technology Survey

- Survey about single line transmission line feasibility, propose the most interesting one, state the basic methodology of analysis and open issue.

- Single line transmission line mode maintenance and excitation

  Investigate detailed technology to excitation and maintain the single transmission mode;
5 Expected Outcome and Deliverables

- Technical reports of survey about single line transmission line feasibility, propose the most interesting one, state the basic methodology of analysis and open issue.;
- Technical report or simulation for detailed technology to excitation and maintain the single transmission mode;

6 Acceptance Criteria

Technology survey reports covers almost present study, related technique aspects are covered, well logic organized;

Clear novel analysis method is stated;

7 Phased Project Plan

- Phase1 (~4 months): Survey about single line transmission line feasibility, propose the most interesting one, state the basic methodology of analysis and open issue.
- Phase2 (~9 months): Investigate detailed technology to excitation and maintain the single transmission mode;
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Sparse Measurements in Radio Transmission Technology

1 Theme: Wireless Communication Technology

2 Subject: Radio Transmission Technology

3 Background

Today the main trends in wireless communication become obvious. Such 5G network assumes bandwidth growth from 20MHz up to 400MHz in sub 6GHz range; the same time massive-MIMO is also a way to improve capacity of the system in limited spectrum resources. Another important part is expected cost of the massive-MIMO system. So, one of the main trend in the system development is hybrid (analog+digital) radio chain part that is also limit channel measurements, and required smart approach for channel recovery. Indeed, communication system has to match with propagation channel to achieve high capacity rates. Thus, channel acquisition becomes important problem in high dimension system with limited amount of pilots. Further pilot growth will bring additional overhead and reduces effective capacity of the system. It is well known an effective channel has coherence properties in subcarrier-symbol-antenna dimensions. Thus, it is reasonable to develop self-adjusted sparse reference signal for partial channel measurement, and recover unmeasured parts of the channel by solving low-rank matrix completion problem.

**Low-rank matrix completion problem**
Due to the low-rank nature of high dimensional effective channel, we can recover missing entries of the matrix and improve system resolution. Let define $\Omega \subset \{1,2,3,...,m\} \times \{1,2,...,n\}$ be an index set consisting of the location of the observed entries (reference signal responses). Suppose we have a measurement matrix $X$, which is supported on $\Omega$ and satisfies:

$$[X]_{ij} = [H]_{ij}, \quad \forall (i,j) \in \Omega,$$

where $H \in \mathbb{C}^{m \times n}$ is the desired matrix to recover each column in which is a data point lying on some low-dimensional subspace.

**Multidimensional signal interpolation outside of conservative coherence interval**
Assume, we have multidimensional signal as following

$$Y = RAXR_B \in \mathbb{C}^{N_A \times N_B},$$

where $R_A \in \mathbb{C}^{N_A \times N_A}$, $R_B \in \mathbb{C}^{N_B \times N_B}$ is symmetrical autocorrelation complex (Hermitian) matrixes, $X \in \mathbb{C}^{N_A \times N_B}$ is a random complex matrix with independent values. We can construe matrix $Y$ that it consist of $N_B$ random vectors $y^{(i)} = [y_1^{(i)}, y_2^{(i)}, ..., y_N^{(i)}]_T, i \in [1, N_B]$ size of $N_A$ dimension. Matrix $R_A$ determine correlation properties in the first dimension and is constant for any column of $Y$. Matrixes $R_B$ determine correlation properties in the
second dimension of random values \( y^{(i)}_j \) in measurement points (figure 1), \( j \in [1, N_A] \) that according random values variation in time domain on the time interval \( t \in [0, T] \). Vector column \( y \) is a periodical definition of random process in the time moments \( t_k = k \cdot T_S \), \( k \in [0, N_B - 1] \), with period \( T_S = \frac{T}{N_B - 1} \). Let us to define \( \tilde{Y} \) as decimated version of \( Y \) by second dimension

\[
\tilde{Y} = R_A X r_B \in \mathbb{C}^{N_A \times N_B'},
\]

where \( m = \frac{N_B}{N'_B} \in \mathbb{N}, m \gg 1 \) is decimation ratio (in this task can be considered 10 or 20),

\( r_B \in \mathbb{C}^{N'_B \times N'_B}, r_B \subseteq R_B \).

Properties of signal \( Y \):

- Norm of each column of \( Y \) or \( \tilde{Y} \) is equal one (unit norm): \( \| y^{(i)} \|_2 = 1, \forall i \in [1, N_B] \).
- Matrix \( X \) consists of independent random values (\( E[XX^H] = E[X^HX] = I \)).
- Matrixes \( R_B \) determine correlation properties in time domain and can be represent by

  Bessel function of zero order \( R_B \approx (w_1j_0(w_2t))^H \times (w_1j_0(w_2t)) \), where \( w_1, w_2 \) is some coefficients of proportion (on the figure 2 is present example of module correlation function by first row).
- Period \( T_S \) can variate in wide range and belong some time interval, \( T_S \in [a, b] \). (see figure 2).

---

*Figure 1 – 2D Measurement set: horizontal means random time sequence with defined*
oscillating correlation function (bottom side diagram); vertical means different time
sequence samples/realizations, which are also linked by exponential correlation
function (right side diagram)

Figure 2 – Example of correlation function $|R_B|$ and interval of task’s interest $(a, b)$

Full-dimension channel recovery problem in HBF system
Sparse measurements are possible in different cases. The most obvious example is
limited amount of reference signals to reduce system overhead, and let more resources be
used for data transmission. But there is also another case, when potential cost reduction
bring us to well known hybrid beamforming, when we want to keep antenna resolution and
antenna gain, but reduce receiver/transmitter hardware costs. In this case, “full digital
solution” reduced to partly digital – partly analog solution.

Figure 3 – Conditional representation “full digital” solution splitting into digital and analog parts.
Note: analog part becomes the part of the air/propagation channel during channel measurement procedure. Thus,
legacy channel estimation techniques cannot be applied to recover full dimensional channel.

Thus, all channel knowledge sensitive algorithms have less resolution rather “full digital”
case, and problem of channel recovery in term of resolution improvement becomes
important.

HBF System Model:
In the Uplink channel, estimation process the received pilot signal $Y \in \mathbb{C}^{N_D \times N_{UE}}$ observed
in the “digital domain” size $N_D$ of the BS with $N_A$ antenna ports is as follows:

$$Y(i) = W_A^H(i)H_p + W_A^H(i)\eta = H_{eff}(i)p + \xi,$$

where $H \in \mathbb{C}^{N_A \times N_{UE}}$ is the channel matrix (let consider single user channel measurement
\(N_{\text{UE}} = 1\); \(W_{\text{A}} \in \mathbb{C}^{N_{\text{A}} \times N_{\text{D}}}\) is the analogue beamforming weight matrix; \(H_{\text{eff}}(i) \in \mathbb{C}^{N_{\text{D}} \times N_{\text{UE}}}\) is the effective channel matrix in the “digital antenna port” space observed at \(i\)th iteration, \(\mathbf{n}\) is the noise vector, \(\xi\) is the effective noise vector, \(p\) is the transmitted Uplink pilot signal, \(i\) is the index of a channel measurement iteration, and \((\cdot)^H\) represents the Hermitian conjugate operation.

The specifics of the beamforming in antenna array with limited number of RF chains (HBF) is that

1. The entire full-dimensional channel matrix \(H\) cannot be estimated at once; only \(H_{\text{eff}}\) can be estimated in digital domain during one channel measurement iteration;
2. \(H_{\text{eff}}(i)\) depends on the \(W_{\text{A}}(i)\).

After a series of channel measurement iterations with different \(W_{\text{A}}(i)\) the full-dimensional channel matrix can be obtained via a combination of the estimated \(H_{\text{eff}}(i)\) using a functional \(F\) as follows:

\[
\tilde{H} = F(H_{\text{eff}}(1), H_{\text{eff}}(2), \ldots, H_{\text{eff}}(N)).
\]

Therefore the problem is to find a set of \(W_{\text{A}}\) and the corresponding functional \(F\) to reconstruct the estimated channel matrix \(\tilde{H}\) so that

\[
\|\tilde{H} - H\| \rightarrow \min. \quad (*)
\]

**Note:** required channel estimation \(\tilde{H}\) is necessary for L2 algorithms like MU user pairing, thus basic requirement (* ) can be reconsidered in terms of sufficient accuracy for L2 algorithms. Of course, number of iterations have to be as minimal as possible to allow quick response from scheduler on scheduling request. When, such channel reconstruction has been done, and users have been scheduled, then DL MU HBF precoder will be calculated according pairing user set.

### 4 Scope

Thus, in all mentioned above use cases, it is required channel information recovery from limited measurement set. Scope of this project is identify a way to resolve this bottleneck problem and improve resolution of massive-MIMO system under defined constraints. It might be theoretical approach that can be used in all mentioned cases, or it could be case-by-case solution for following tasks:

- Channel information recovery under limited pilot overhead (sparsified pilots);
- Channel interpolation or equivalent extension for time coherence interval;
- Channel information recovery in HBF solution.
5 Expected Outcome and Deliverables

Problem #1:
1.1 How to define index set $\Omega$, which is optimal for known $\mathbf{H}$ in terms of entry recovery:
$$\mathcal{P}_\Omega(\mathbf{X} - \mathbf{H}) \rightarrow 0,$$
where $\mathcal{P}_\Omega$ denotes the orthogonal projection onto the linear space of matrices supported on $\Omega$.
How optimality condition can be linked with system performance metrics (like system throughput or edge SNR)?
Note: is it enough to provide sparse measurements (to estimate several entries in the channel matrix)? Or each entry measurement can be defined as linear (or non-linear) combination of the estimated matrix entries?
1.2 Given the measured matrix $\mathbf{X}$ and the index set $\Omega$, can we exactly recover the target matrix $\mathbf{H}$ in a scalable way?

Problem #2:
2.1 As input, we have signal $\tilde{\mathbf{Y}} \subseteq \mathbf{Y}$, which is decimated version of signal $\mathbf{Y}$. Correlation function $\mathbf{R}_A$ is fixed and can be submit by requirement for simulation, or can be simply approximated by exponential correlation function on initial stage of research. It is necessary to design an algorithm of multidimensional signal recovering

$$\tilde{\mathbf{Y}} \overset{\mathbf{B}}{\rightarrow} \hat{\mathbf{Y}} \approx \mathbf{Y}$$
and $\tilde{\mathbf{Y}} = \mathbf{R}_A \mathbf{X}_B \mathbf{B}$, where $\mathbf{B} \in \mathbb{C}^{N_B \times N_B}$ is a some operator of recovering (interpolation) on the interval $[0, T_S]$. Accuracy of interpolation can be evaluated as correlation between recovered matrix $\hat{\mathbf{Y}}$ and original $\mathbf{Y}$:

$$\hat{\mathbf{Y}}^H \mathbf{Y} = \left( \mathbf{B}^H \mathbf{r}_B^H \mathbf{X}^H \mathbf{R}_A^H \mathbf{Y}^H \right) \mathbf{Y} = \mathbf{B}^H \tilde{\mathbf{Y}} \mathbf{Y},$$

then, interpolation operator $\mathbf{B}$ has to satisfy condition:

$$\sup_{\frac{N_B}{N_B'}} \text{trace}(\mathbf{B}^H \tilde{\mathbf{Y}} \mathbf{Y}) \rightarrow N_B, \quad 20 < m_0 < m_{\max} \tag{*}$$

2.2 In case of mentioned above input data is not enough, what kind of additional assumption has to be introduced?
2.3 If we take “left” L -boundary condition as zero point, how can we identify location of “right” R -boundary point (figure 1) on the correlation diagram (figure 2) on interval $[a, b]$? Can such information (location in 2nd or 3rd sidelobe of correlation function) help in design of interpolation matrix $\mathbf{B}$?
2.4 Finally, it is expected theoretical research report and numerical algorithm for interpolation on interval $[0, T]$.

Problem #3
3.1 How to choose initial $\mathbf{W}_A$ for usage in MU-scheduling algorithms?
What is $F$ in this case?
3.2 How to minimize the number of channel measurement iterations $N$?
3.3 How to choose the optimal analog port mapping?

3.4 Considering L2 algorithms, requirement (*) is always sufficient, but not necessary. Can be introduced some minimal necessary condition, which allows simplify and/or speed up full dimension CSI recovery for L2 purpose?

3.5 Algorithm for CSI recovery: extension digital port dimension to full port dimension, allowing multi-user scheduler occupies more spatial layers than just CSI based on digital port measurements.

Deliveries are considered in form of technical reports with detailed description of theory and algorithms, as well as simulation results showing potential benefits from the proposed methods/algorithms.

6 Acceptance Criteria

The proposed methods should be implementable (algorithm complexity issue), can improve system performance at least 30% with similar constraints on legacy solution;

The benefit is reasonable theoretically, it is preferable new theory introduction about sparse measurements and its post-processing. All achievements have to be proved by the simulation evaluation;

No needs to implement the whole protocol stack and the whole RRM schemes in the platform, pure physical layer enhancement is also acceptable given reference signal distribution is reasonably modeled.

7 Phased Project Plan

Phase 1 (~3 months): analysis of existing mathematical methods and computational algorithms, which can be used for information recovery based on sparse measurement set.

Phase 2 (~5 months): development algorithms for channel information recovery based on

- limited amount of pilot during some time interval (mobility scenario with short coherence time), and channel interpolation for system resolution improvement;
- limited antenna port number in HBF architecture that doesn’t allow to obtain channel from single measurement process.

Phase 3 (~4 months): theory and/or rules development to optimize pilot mapping on the sparsified measurement set targeting the best system performance with minimal channel measurements. Adaptive mapping algorithm to different channel conditions.
The new beam-forming architecture of 5G Wireless Communication

1 Theme: Wireless Communication Technology

2 Subject: Architecture of Base Station equipment

3 Background

3.1 A classification and summary of current 5G BS architecture

<table>
<thead>
<tr>
<th>Classification</th>
<th>Advantage</th>
<th>Disadvantage</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. AIP/AHBF Architecture</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. DBF Architecture</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### 1. DBF

<table>
<thead>
<tr>
<th>Number of Beams and Beam-Direction</th>
<th>Number of Used DIF Channel</th>
<th>Sub 6GHz Massive MIMO Architecture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can be Configured Arbitrarily</td>
<td>Is Too Much, So Power Dissipation is High</td>
<td>32TRX/64TRX/128TRX.. (IF BW&lt;100M)</td>
</tr>
<tr>
<td>According to Application</td>
<td>and Cost is Too High to Be Deployed Massively</td>
<td></td>
</tr>
<tr>
<td>All the Beams Use Whole Antenna Array</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 2. AIP/AHBF

<table>
<thead>
<tr>
<th>Save Cost and Power Dissipation of the Device</th>
<th>Only Support Some Group-Beam Deployment and Number of Beams is Not Enough, Flexibility of the Beam is Low and Time Delay of Whole System Becomes Severely Especially for Massive User Scene</th>
</tr>
</thead>
<tbody>
<tr>
<td>Because of Reduction of DIF Channels</td>
<td>High Frequency Massive MIMO Architecture (IF BW&gt;800M for Each Channel, High EIRP)</td>
</tr>
</tbody>
</table>

---

So our problem is how to find a new architecture for 5G base station, an architecture can both support beam-flexibility/time&frequency resource redistribution and lower cost/lower power dissipation.

### 3.2 Some new architecture discussion (only for reference)

1. DIF POOL architecture
This architecture can be configured as DBF or AHBF simply by adjust the DIF POOL module, you only need change the digital and analog channel mapping mode for use.

2. Antenna Field Hybrid Beam Forming architecture

DBF -> DHBF -> AHBF/AiP -> FHBF

**FHBF**: Field HBF

<table>
<thead>
<tr>
<th>Architecture</th>
<th>Block Diagram</th>
<th>Cost</th>
<th>Size</th>
<th>Challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Holographic Beam</td>
<td></td>
<td>Super-sampled COTS design enables low price</td>
<td>Thin, Conformable</td>
<td>Single beam per polarization per sub-aperture.</td>
</tr>
<tr>
<td>Array</td>
<td></td>
<td>Distributed phase shifters and amplifiers pushes moderate price</td>
<td></td>
<td>Thermal challenges difficult due to distributed amplification. Multi-beam significantly increases cost (more phase shifters, distribution layers)</td>
</tr>
<tr>
<td>MIMO</td>
<td></td>
<td>Radios behind every element and complex BBU drives high price and power consumption</td>
<td>Usually thick but antenna thickness can be reduced by hiding BBU in baseband cabinet</td>
<td>No FDD Unworkable at mmW Spectral Efficiency vs. cost scales poorly</td>
</tr>
</tbody>
</table>

This architecture use the antenna field technology to form the user-beam, replace the ordinary phase-shifter and reduce the cost of device.
4 Expected Outcome and Deliverables

Only for an example, the details of this project outcome can be discussed clearly when project is setting up.

<table>
<thead>
<tr>
<th>Num</th>
<th>Outcome</th>
<th>Description</th>
</tr>
</thead>
</table>
| 1   | A Xxx architecture for 5G application | • The report of survey and design for xxx architecture  
• The relevant simulation of the system algorithm or some important module  
• The relevant patent of this architecture  
• Some module test for proving the architecture is beneficial |

5 Acceptance Criteria

• Design and survey report:  The theory is reasonable and the architecture is really beneficial  
• Simulation report:  The simulation result is reasonable  
• Patent:  pass Huawei technical review  
• Module test:  The test data is reasonable and can be remade

6 Phased Project Plan （Only for example, the detail can be discussed clearly when project is setting up）

<table>
<thead>
<tr>
<th>Phase</th>
<th>Begin</th>
<th>End</th>
<th>Target</th>
<th>Outcome</th>
</tr>
</thead>
</table>
| 1     | T     | T+4  | Finish the survey and design of the new architecture | 1. the survey and design report  
2. the new patent |
The actual beginning and ending time can be discussed again according to the real process of project, we only suggest to divide 3 phases: The first phase start up the project and finish the survey and design job, the second phase finish the theory and simulation job, then the last phase give a module test to prove this architecture if it is possible.
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Without the written consent of Huawei Technologies Co., Ltd, this document cannot be distributed except for the purpose of Huawei Innovation R&D Projects and within those who have participated in Huawei Innovation R&D Projects.
Topological layout and element arrangement Research for M-MIMO array antenna

1 Theme: Future M-MIMO Antenna array

2 Subject: Antenna array Architecture and performance

3 Background

Massive MIMO is going to one of the key techniques in the 5th generation communication since M-MIMO can increase 10 times or more capacity and improve the radiated energy efficiency on the order of 100 times. The increasing capacity results from the spatial multiplexing in M-MIMO systems and the dramatic increasing of energy efficiency is caused by a large number of antennas. These antennas becomes an array which can focus the energy into small regions because of the coherent superposition of wave fronts. The array antennas can shape the signal and help the base station to emit the wavefronts collectively. The array antenna can influence the performance of M-MIMO. Thus, the research on the topology of antenna array is essential for M-MIMO.

The traditional antenna researches focus on the polarization, mutual coupling and so on; while the traditional L1/L2 pay attention to the algorithms itself such as interference suppression in MU MIMO. This project hope to combine the antenna and algorithms together to study the topology characteristics for improving M-MIMO performance especially for MU performance. This project focus on topology study, which can give a methodology to design a new high performance antenna array instead of traditional planar rectangular based antenna array.

4 Scope

➢ The structure study

The arrangement of Antenna element
Investigate the connection between antenna element position and performance (including array performance and system performance) aiming at the optimal H/V arrangement in the limited the range;

The Structure of Antenna element

Investigate the array spatial structure, traditional M-MIMO is proposed where antennas are placed in a 2D grid, Moreover 3D and distributed array structures are candidates as well.

Or, Investigate the performance of array connection to the RF port, and so on;

➢ The array shape study

Investigate the performances of array shape such as planar line or planar circular, rectangular or cylindrical or spherical, especially for the **MU-performance**.

5  Expected Outcome and Deliverables

- Technical reports of different structures of antenna array, such as 2D or 3D placement, H/V arrangement, element connection, including the structure design and performance analysis;
- Technical reports of different shapes of antenna array, such as planar line or planar circular, rectangular or cylindrical or spherical, including the structure design and performance analysis;
- Related simulation platform with source codes and description
- 1~2 Invention/patents;

6  Acceptance Criteria

Design a new topology antenna array in M-MIMO and ensure good MU–MIMO performance at least NOT worse than the traditional M-MIMO array structure;
7 Phased Project Plan

- Phase 1 (~3 months): survey the topology research of antenna array in M-MIMO especially for MU technology, analyze and provide the related technical report.

- Phase 2 (~6 months): research on the array structure analysis and design, including array sharp, array performance, system performance and provide the related technical report.

- Phase 3 (~3 months): research and provide related structure design, algorithms, simulation results and patents.
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Traffic Profiling for Scheduling Efficiency in 5G

1 Theme: Wireless Communication Technology

2 Subject: Traffic Profiling for Scheduling Efficiency in 5G

List of Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AI</td>
<td>Artificial Intelligence</td>
</tr>
<tr>
<td>ML</td>
<td>Machine Learning</td>
</tr>
<tr>
<td>SPS</td>
<td>Semi Persistent Scheduling</td>
</tr>
</tbody>
</table>

3 Background

4G cellular radio access networks allow policy enforcement and scheduling based on L2/L3 information at user or session granularity. However, today’s networks are agnostic to higher layers unless the applications themselves (or the hosts where they run) use some kind of mechanism to inform the scheduler about the application that originates a traffic session. Such a solution is hard to apply in several scenarios since it implies either cooperation from the applications or the installation of software in the user devices. Traffic classification can provide application layer knowledge to the scheduler allowing application based access policies and/or routing. This however has to be performed online in order to classify a session after only a few of its initial packets.

Traditionally transport layer port information and the direct inspection of the packet’s payload (DPI) have been used for traffic classification. However, both approaches have several shortcomings. Port information has become obsolete since applications mostly use the same transport port (usually the well known port for HTTP or HTTPS) or dynamic port negotiating mechanisms. Packet Inspection suffers with the increasing use of encrypted
traffic which is becoming the norm in most applications. Artificial Intelligence (AI) algorithms,
more specifically, Machine Learning (ML) ones, have been considered in more recent literature for traffic classification.

In order to have application aware policy and/or scheduling, we need online classification. This implies that all the data the classifier requires to make its decision must be obtained from the first packets at the beginning of a flow so that action can be taken on the remaining traffic.

4 Scope

The scope of this research topic is to develop methods to profiling the user traffic behavior and classifying among the different applications. A motivation for profiling the traffic is that certain traffic can be more efficiently scheduled. Profiling the traffic and distinguishing among different traffic/application types on the fly can be performed by means of traffic pattern recognition using ML. By quickly identifying a traffic model it will enable smart steering and scheduling decisions. Furthermore, identifying repetitive patterns and traffic mixes will allow for predictable traffic which can be taken care by a semi persistent scheduler which is computationally cost effective as compared to a dynamic scheduler that operates on a per TTI basis.

The objectives of this research area include:

- The traffic modelling parameters that will be used to classify and predict traffic, such as, burst density within the macroburst (throughput per burst), packet size distribution per reception occurrence (smaller than a burst), packet inter arrival distribution (e.g. pareto or exponential), and longer initial buffering burst followed by shorter bursts.
- The investigation of appropriate machine Learning tools to identify and classify a stream on the fly and whether it should be subject to semi-persistent scheduler.
- The development of methods that can predict traffic bursts on a macro level from the first packets at the beginning of a session and can be used to better predict the data
demand and cell load ahead of time

5 Expected Outcome and Deliverables

- Technical reports on the modelling parameters of traffic to be used for pattern recognition.
- Technical reports on ML methods to be used for the purpose of pattern recognition.
- Technical reports on the application of the modelling parameters for learning and traffic recognition/classification.

6 Acceptance Criteria

Proof of concept based on the implementation of the developed algorithms for different traffic profiles in evaluation simulation studies.

7 Phased Project Plan

Phase1 (~3 months):
Analyze the traffic modelling parameters that can be used for the classification of traffic.

Phase2 (~3 months):
Research and propose appropriate ML methods for the classification of traffic.

Phase3 (~6 months):
Research and provide related algorithms and simulation results.
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Upper Bound Rate Research for Coordinated Downlink Precoding in Wireless Cellular Networks

1 Theme: Wireless Communication Technology

2 Subject: Downlink Coordinate Technology

3 Background

Wireless systems continue to strive for ever higher data rates. With the ever increasing traffic demand, cellular networks are becoming more and more dense. The available rate is limited by the inter-cell interference. Coordination among base stations (BSs) has been widely studied in the recent years to tackle it. These techniques known in the industry as coordinated multi-point (CoMP), are classified into (a) coordinated scheduling/beamforming (CS/CB), which requires channel state information (CSI) but no data sharing among the BSs, and (b) joint processing (JP), which requires both CSI and data sharing among the BSs. Our project focuses on downlink CoMP-CB where BS only serves its own UEs without sharing with other BSs. For time-varying MIMO channels there are multiple Shannon theoretic capacity definitions and, for each definition, different correlation models and channel information assumptions should be consider. [1] provide a comprehensive summary of ergodic capacity. A brief summation table is as follows:

<table>
<thead>
<tr>
<th>Scenes</th>
<th>CSIR, CSIT</th>
<th>CSIR, CDIT(ZMSW)</th>
<th>CSIR, CDIT(CMI)</th>
<th>CSIR, CDIT(CCI)</th>
<th>CDIR, CDIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single cell SU-MIMO</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>×</td>
</tr>
<tr>
<td>Single cell MU-MIMO</td>
<td>✓</td>
<td>×</td>
<td>×</td>
<td>×²</td>
<td>×</td>
</tr>
<tr>
<td>Multiple cell MU-MIMO</td>
<td>✓¹</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
</tr>
</tbody>
</table>

Note:

1. WMMSE based solution is given in [2] for multiple cells MIMO channel with CSIR and CSIT

2. WMMSE based solution is given in [3] for single cell MISO channel with CSIR and CDIT(CCI)
3. Abbreviations:

CSI: Channel State Information

CSIT: Transmitter Channel State Information

CSIR: Receiver Channel State Information

CDIT: Transmitter Channel Distribution Information

CDIR: Receiver Channel Distribution Information

ZMSW: Zero Mean Spatially White, $\mathbb{E}[\mathbf{H}] = 0, \mathbf{H} = \mathbf{H}^w$

CMI: Channel Mean Information, $\mathbb{E}[\mathbf{H}] = \bar{\mathbf{H}}$, $\mathbf{H} = \bar{\mathbf{H}} + \sqrt{\alpha} \mathbf{H}^w$

CCI: Channel Covariance Information, $\mathbb{E}[\mathbf{H}] = \mathbf{0}$, $\mathbf{H} = (\mathbf{R}_r)^{1/2} \mathbf{H}^w (\mathbf{R}_t)^{1/2}$

DPC: Dirty Paper Coding

In table 1, CSIR and CSIT (the 2nd column) mean that the downlink CSI is known by UE and BS respectively. CSIR and CDIT (CCI) (the 5th column) mean that the downlink CSI is only known by UE and BS just know downlink channel distribution information. The former represents TDD mode where BS can get CSI by reciprocity and the latter represents FDD mode where BS can only get transmission correlation matrix. We mainly focus on these two modes.

For convenience, we use TDD mode and FDD mode to represent CSIR&CSIT and CSIR&CDIT (CCI) respectively in the following chapters.

4 Scope

4.1 TDD mode (CSIR&CSIT)

In TDD mode, [2] provide WMMSE based solution to maximum system throughput which is implemented by joint iteration between BSs’ precoding matrix and UEs’ receiver. The assumption is that all the channels including serving channels in intra cells and interfering channels in intra and inter cells in the network should be known. For example, for some UE in the network in fig 1 left, all downlink CSI from 19 cells to this UE should be known.

But in reality, not all the channels can be measured because of the protocol limitation and measurement accuracy. For example, for UE1 and UE2 in fig 1-right, they have only measure partial channels in the network. UE1 is located in the edge between cell0, cell5 and cell6, so it can only get downlink channels from these three cells. And similarly, UE2 can only get channels from cell0, cell2, cell3 and cell4. If those unavailable channels is set to zero matrix then the throughput getting from WMMSE will less than the ideal case.
So the first requirement is how to close to the ideal performance when only partial channel is known. That is what assumption should be done to those unavailable channels.

![Cellular wireless network demonstration](image)

**fig1.** Cellular wireless network demonstration

### 4.2 FDD mode (CSIR&CDIT (CCI))

In FDD mode, only [3] provide WMMSE based solution for single cell MISO channel. It’s still blank for multi cell MIMO channel.

So, the second requirement is to get the maximum throughput of the network when every CSIR&CDIT (CCI) is known.

The third requirement is how to close to the maximum throughput of the network when partial CSIR&CDIT (CCI) is known, which case is similar with the first requirement.

### 4.3 Summary

#### 4.3.1 Signal model

Consider multicell scene with $K$ BSs. The $k$th BS with $M_k$ Tx antennas can serves $I_k$ UE with $N_{i_k}$ Rx antennas in this BS. Then the received signal of $\text{UE}_{i_k}$ which is the $i$th UE in BS $k$ is:

$$
y_{i_k} = H_{i_k}V_{i_k}s_{i_k} + \sum_{j=1, j \neq i}^{I_k} H_{i_j}V_{i_j}s_{i_j} + \sum_{k' = 1, k' \neq k}^{K} \sum_{j=1}^{I_{k'}} H_{i_{k'}}V_{i_{k'}}s_{i_{k'}} + n_{i_k}
$$

$\forall i_k \in \mathcal{I}$, $\mathcal{I} = \{i_k| k \in \{1,2, ..., K\}, i \in \{1,2, ..., I_k\}\}$

---

3 / 7
In which

The first item is target signal, the second item is the interference from the same cell, and the third item is the interference from other cells.

\( \mathcal{X} \) is the set including all UEs. The total number of BSs is \( K \). The UE in BS \( k \) is indexed by \( i_k \) and the total number is \( I_k \).

\( y_{i_k} \in \mathbb{C}^{N_{i_k}} \) denotes the received vector of \( \text{UE}_{i_k} \).

\( H_{i_k} \in \mathbb{C}^{N_{i_k} \times M_k} \) denotes the serving channel form BS \( k \) to \( \text{UE}_{i_k} \) in same cell

\( H_{i_kj} \in \mathbb{C}^{N_{i_k} \times M_j} \) denotes the interference channel form BS \( j \) to \( \text{UE}_{i_k} \) in BS \( k \).

\( V_{i_k} \in \mathbb{C}^{M_k \times d_{i_k}} \) denotes the Tx BF matrix to \( \text{UE}_{i_k} \).

\( s_{i_k} \in \mathbb{C}^{d_{i_k}} \) denotes the Tx modulated symbol vector of \( \text{UE}_{i_k} \), satisfied \( E[s_{i_k}s_{i_k}^H] = I \)

### 4.3.2 Maximization problem

The weighted sum rate maximization can be written as:

\[
\max_{\{V_{i_k}\}_{k=1}^K} \sum_{k=1}^K \sum_{i_k=1}^{I_k} \alpha_{i_k} R_{i_k}
\]

s. t. \( \sum_{i_k=1}^{I_k} \text{Tr}(V_{i_k}V_{i_k}^H) \leq P_k, \forall k = 1, 2, ..., K \)

where \( R_{i_k} \) is the rate of \( \text{UE}_{i_k} \) which can be written as:

\[
R_{i_k} \triangleq \log \det \left( \sigma^2 I + \sum_{i=1}^{I_k} H_{i_k} V_{i_k} V_{i_k}^H H_{i_k}^H + \sum_{k' \neq k}^K \sum_{j=1}^{I_{k'}} H_{i_kk'} V_{j_k} V_{j_k}^H H_{i_kk'}^H \right) - \log \det \left( \sigma^2 I + \sum_{j \neq i}^{I_k} H_{i_kj} V_{j_k} V_{j_k}^H H_{i_kj}^H + \sum_{k' \neq k}^K \sum_{j=1}^{I_{k'}} H_{i_kk'} V_{j_k} V_{j_k}^H H_{i_kk'}^H \right)
\]

\[
= \log \det \left( I + H_{i_k} V_{i_k} V_{i_k}^H H_{i_k}^H \right) \left( \sigma^2 I + \sum_{(j,k')} (j,k) \neq (i,k) H_{i_kj} V_{k'} V_{k'}^H H_{i_kj}^H \right)^{-1}
\]

\( \alpha_{i_k} \) is used to represent the priority of \( \text{UE}_{i_k} \) in the system.

\( P_k \) is BS \( k \)'s power limitation.
4.3.3 TDD mode

For TDD’s 1st requirement, BSs know partial $H_{ikj}$ in the network.

$$\forall i_k \in I, \quad I = \{i_k | k \in \{1,2,...,K\}, i \in \{1,2,...,I_k\}\}$$

$$\forall j \in \{1,2,...,K\}$$

How to close to the ideal maximum throughput? Is it necessary to do some assumption to those unavailable $H_{ikj}$, or something else? How to reduce the implement complexity?

4.3.4 FDD mode

For FDD’s 2nd requirement, how to get the maximum throughput of the network when BSs only know CCI, that is $E[H_{ikj}H^H_{i'k'j'}]$.

$$\forall i_k \in I, \quad I = \{i_k | k \in \{1,2,...,K\}, i \in \{1,2,...,I_k\}\}$$

$$\forall i'_{k'} \in I, \quad I = \{i'_{k'} | k' \in \{1,2,...,K\}, i' \in \{1,2,...,I_{k'}\}\}$$

$$\forall j,j' \in \{1,2,...,K\}$$

For FDD’s 3rd requirement, how to close to the ideal maximum throughput when partial CCI is available to BSs? Is it necessary to do some assumption to those unavailable $H_{ikj}$ or something else?

5 Expected Outcome and Deliverables

- Technical reports of the three requirements above mentioned.
- Matlab code of the solutions for the three requirements.
- 1~2 invention/patents.

6 Acceptance Criteria

- The solution needed to be justified in theory. If only suboptimal solution is available, then simulation comparison with other methods is needed to verify its performance.
- The Matlab code need to run to show the results in technical reports. Function without source code is not acceptable.
7 Phased Project Plan

Phase 1 (~3 months): The state-of-the-art investigation report of CoMP-CB in wireless cellular networks.

Phase 2 (~4 months): the technical reports and matlab code for requirement 1

Phase 3 (~5 months): the technical reports and matlab code for requirement 2 and 3.

参考资料清单 List of reference

[1]. A. Goldsmith; S. A. Jafar; N. Jindal; S. Vishwanath, "Capacity limits of MIMO channels", IEEE Journal on Selected Areas in Communications


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