PoC of SCMA-Based Uplink Grant-Free Transmission in UCNC for 5G

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***Abstract*— A 5G mobile network has evolved from a cell centric radio access network to a user centric one. A user-centric no-cell (UCNC) framework has been proposed, which enables physical layer coordination over a large number of transmission and reception points for each mobile user to always experience cell-center-like communications. This paper presents some key technologies in the UCNC framework. The focus is on proof of concept of UL grant-free transmissions in the UCNC architecture. Massive connectivity supporting a huge number of devices is one of the three important scenarios in 5G networks. The challenges to support massive connectivity lie in the cost of signaling overhead and transmission latency. An uplink grant-free transmission based on sparse code multiple access (SCMA) design is proposed. The proposed scheme can provide different levels of overloading to efficiently meet the massive connectivity requirements. Grant-free transmission conducted in RRC connected state can reduce signaling overhead, while in energy conserved operation (ECO) state, it can significantly reduce the user plane transmission latency. Extensive laboratory testing has been conducted in a collaborative project of Huawei and Telefonica to verify the performance matrices. Taking LTE as a baseline for comparison purposes, it is shown that the signaling overhead by using uplink grant-free transmission can be reduced by around 80% and the user plane transmission latency in ECO state can be reduced by around 93%. Moreover, massive connectivity is efficiently supported with the SCMA scheme that yields around 230% gain over OFDMA in terms of supported active users.**

***Index Terms*— 5G, UCNC, ECO state, UE tracking, grant-free transmission, SCMA, massive connectivity, signaling overhead, transmission latency.**

I. Introduction

5G wireless networks are expected to support very diverse scenarios, such as broadband everywhere even in ultra dense area, as high as 500km/h user mobility, massive connectivity from all types of low cost devices, ultra low latency for virtual reality and ultra reliability for industry control, V2X [1]. To fulfill these service requirements, more challenging performance indicators such as 1ms transmission delay, 100x higher data rate, 1000x more connections need to be provided compared to current 4G networks. Though these requirements are not necessarily to be met at the same time, any one of them may initiate the revisit of the mobile networks.

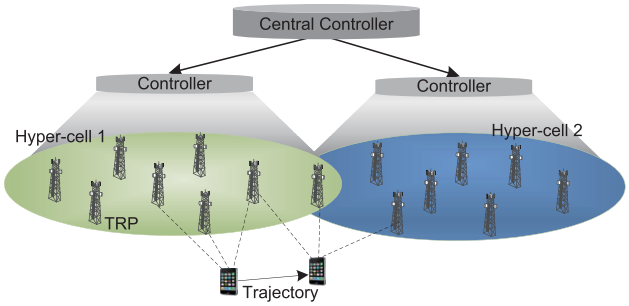


Fig. 1. UCNC network architecture.

A novel radio access framework has been evolved from traditional cell centric access to user centric access based on hyper-cell abstraction. A hyper-cell is formed with one or many transmission and reception points (TRPs). A TRP can be a macro eNB, a pico eNB, an RRU or any other kind of light node. Hyper-cell concept decouples UE from physical cell site and simplifies heterogeneous node deployment [2]. A hyper-cell based user-centric no-cell (UCNC) network architecture is shown in Fig. 1 where centralized data processing and hierarchical control logical is applied. UCNC can enable large scale coordination of many TRPs for consistent user experience provisioning across network. Many new technologies and terminologies have been derived in UCNC framework, for instance, multiple TRPs assisted network synchronization, a new Energy Conserved Operation (ECO) state and UE tracking in ECO, grant-free based UL access both in RRC Connected and ECO state, coordinated UL/DL transmission, to list a few. Proof of concept (PoC) has been conducted to verify the feasibility and effectiveness of the newly proposed technologies. This paper presents an overview of phase I prototype of UCNC with the focus on UL grant-free transmission for massive connectivity support.

Massive connectivity with a large number of devices including smart phones, tablets and mostly of low cost sensors and machine is one of the important 5G requirements that needs to be supported. This type of service is characterized by infrequent, small packets in uplink transmission for keeping alive, data reporting or event triggered alarming. For instance,

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periodic humidity data reporting from a cluster of sensors distributed in the basement. As this kind of transmission will initiate frequent state transitions between RRC Idle and RRC Connected, overwhelming signaling overhead will be introduced and accordingly powerful computing resource will be consumed [3]. Besides, scheduling signals will dominate the control signaling overhead with the increasing of traffic load and the number of users. However, the current LTE system is not able to efficiently support massive connectivity due to the limited control resource allocation and non-machine type traffic based design principle.

Uplink grant-free transmission is a promising method to reduce control signaling overhead of scheduling procedure [4]. For efficient radio resource utilization, grant-free transmission is usually contention-based which results in collision among multiple simultaneous transmissions from different users. To address this problem, several novel multiple access schemes have been proposed in which SCMA attracts peopleâĽ™s attention because of its good overloading capability with reliable link quality [5] [6].

Though link level simulations and field trial on SCMA itself has been conducted demonstrating the overloading capability [7], the effect of SCMA-based UL grant-free transmission on the system signaling overhead and latency reduction has not been fully studied and tested. Also, in the UCNC framework, new technological features are introduced and need to be taken into account in system design and testing. The novelty of this paper lies in the first time lab testing of the SCMA-based uplink grant-free transmission for massive wireless connectivity support in UCNC framework. Extensive testing is conducted to verify the performance gains in terms of signaling overhead, transmission latency and the number of supported UEs over LTE system. It is shown that the proposed scheme outperforms LTE system in all aspects. The rest of the paper is organized as follows. Section II will give an introduction of some UCNC features related to uplink grant-free transmission. Section III will give an overview of uplink grant-free transmission based on SCMA multiple access scheme in UCNC framework. Section IV presents the lab testing environment and interface definition. Testing results are also elaborated in section IV, followed by the conclusion remarks and future testing plans in section V.

II. Introduction on UCNC Framework and Related Technologies

One of the main design objectives of UCNC is to enable large scale coordination of TRPs for a UE to experience always cell-center-like data transmission rate across network [8]. For moving UEs, the serving TRPs are dynamically selected and associated without UE notice to achieve seamless handoff throughout the hyper-cell. The serving TRPs are closely coordinated in network synchronization, UE tracking, DL/UL transmissions and etc. as will be elaborated in the following discussion.

A. Multiple TRPs Assisted Network Synchronization

A UE needs to first get synchronized with a base station before it can do data transmission. In a hyper-cell network

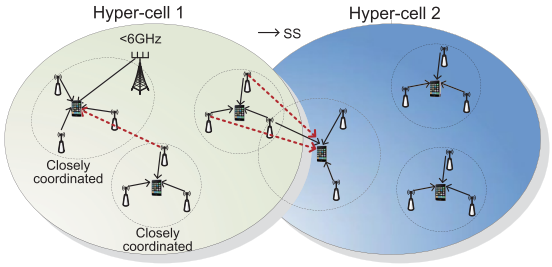


Fig. 2. Transmission of SSs from TRPs within a hyper-cell.

architecture, different TRPs within a hyper-cell can transmit identical synchronization signals (SSs), no matter they are closely coordinated or not. This implies single frequency network (SFN) transmission. As depicted in Fig. 2, a closely coordinated TRP set is formed for each UE. A UE may receive strong enough SSs from the closely coordinated TRPs, and much weaker ones from the rest TRPs in the hyper-cell. It is justified that the initial access from multiple TRPs sending identical SSs with timing arrival differences can achieve better synchronous performance in terms of cell search time and one-shot cell ID detection rate [9]. In our lab testing, LTE SS, both primary SS (PSS) and secondary SS (SSS) are reused and up to 3TRPs within a hyper-cell broadcast identical SSs on the synchronization channel.

B. ECO State in UCNC

To further address the requirement that most of low cost devices, such as sensors, only transmit a small amount of data infrequently, a new state, Energy Conserved Operation (ECO) state is introduced [10] in UCNC network architecture. It inherits the advantage of RRC Idle state in energy efficient operation while alleviates state transition procedure before and after data transmission. In ECO state, three main functions and procedures are defined: notification and system information change monitoring, grant-free transmission and UE tracking. A UE in ECO state, as in RRC Idle, will wake up from time to time as configured to receive network information update. Yet, it differentiates from RRC Idle state in that an inactive UE has its UE context maintained in network so that the complicated authentication, authorization and security setup procedures can be omitted before data transmission. Besides, the backhaul connection between the base station and the serving gateway is also kept so that no bearer establishment is needed. A UE in ECO state somehow acts as an inactive UE in RRC Connected state with long discontinuous reception (DRX) cycles. In this way, an ECO UE can trigger UL transmission in just the same way as in RRC Connected state. Therefore data transmission latency can be greatly reduced due to the alleviation of state transitions to RRC Connected which usually takes more than 100ms for connection establishment. Also it is noted that no scheduling is involved and grant free transmission is applied to further reduce the data transmission delay.

C. UE Tracking in UCNC

To support UL grant-free transmission in ECO state, one critical thing is to let the network know in which TRPs' coverage the UE is located and associate the UE with these TRPs.

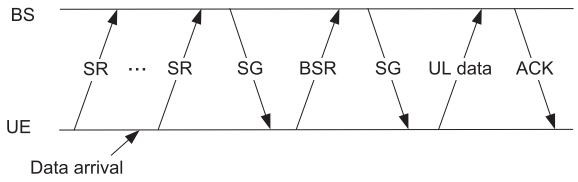


Fig. 3. UL data transmission procedure in RRC connected state.

Because the network has no knowledge of where an ECO UE is located based on traditional DL measurement based cell reselection procedure, some UE tracking scheme needs to be proposed. One possible solution is uplink measurement based UE tracking. UEs in ECO state send out sounding reference signals (SRS) periodically or as requested for the network to locate and measure the UE. Based on different UE capability and mobility requirement, the SRS transmission cycle can be adaptively configured. Interested readers are recommended to refer to [11] and [12] for detailed SRS and UE tracking procedure design. According to the SRS measurements, the network can select and associate a set of optimal TRPs for the UE for possible coordinated transmission and reception. This procedure guarantees that a UE can always be served by closest TRPs for optimal performance achievement. Compared to frequent DL measurement based user mobility supporting, UL measurement is more power efficient in most cases, especially in case with small cells and medium/high mobility [13].

III. Overview of Uplink Grant-Free Transmission Based on SCMA

A. Motivation for UL Grant-Free Transmission

In LTE, uplink transmission follows a request-grant procedure. As shown in Fig. 3, in RRC Connected state, a UE is periodically allocated with a transmission opportunity for scheduling request (SR) transmission to the network. Then the network sends out a scheduling grant (SG) to the UE. If the waiting data cannot be accommodated in the allocated resources, a buffer status report (BSR) is sent out telling the network the volume of waiting data to be transmitted. Finally the network schedules the transmission of the UL data. The procedure involves 4 signaling exchanges before UL data transmission.

Due to the SR resource shortage and the intensive signaling exchanges, request-grant based procedure is difficult to handle massive connectivity. This procedure also brings in long transmission delay. For instance, the SR periodicity is typically 5 or 10ms in LTE. In case when data arrives at the UE right before the SR opportunity, it needs to wait for at least 8 ms before uplink data transmission. The delay is even larger if data arrive in between SR opportunities or the periodicity of SR is configured to be longer. From radio resource utilization perspective, the cost of request-grant is high for small packets since the ratio of signaling overhead to useful payload is high. As analyzed in [5], for a UL transmission of 20B data, the ratio of total resources occupied by the UL grant and UL payload can be around 30%. To reduce signaling overhead, semi-persistent scheduling can be an option. But semi-persistent scheduling is more suitable for periodical than for bursty traffic arrival for efficient radio resource utilization.

The goal of grant-free design is to let UEs transmit data in an arrive-and-go manner. Once the data of a UE arrives, it is transmitted immediately in the next available slot, without waiting for BS to schedule or send grant. The benefits of such transmissions are:

- Overhead reduction in the savings of signaling overhead associated with scheduling request and scheduling grant transmissions.
- Latency reduction associated with latency needed for sending grant request and transmission;
- Energy saving since the UE can remain in DRX longer and able to quickly transmit when data arrives.

With the above performance characteristics, grant-free operation is especially suited for transmissions of large number of infrequent small packets and/or extremely low latency traffic.

UL grant-free transmission can be applied in both RRC Connected and ECO state thanks to the new design concept of ECO state where connection is maintained and grant-free transmission is made possible. For UEs with only infrequent small data packets transmissions, they can be configured to stay in ECO state in normal operation to achieve reduced signaling overhead and transmission delay as well as efficient power saving.

B. SCMA-Based Non-Orthogonal Multiple Access

Grant-free transmission is usually contention-based. In this case, radio resource is predefined and known a priori to UEs. Traditional contention base transmission allows one transmission at a time and multiplexing gain is achieved by time division multiplexing. With the introduction of non-orthogonal multiple access schemes, simultaneous data transmission on the same resource is supported. SCMA as a non-orthogonal multiple access scheme can provide different levels of overloading factors [6] to efficiently meet the massive connectivity requirements. At the transmitter, coded bits are mapped to codewords in complex domain and then spread onto the physical resource elements (REs) of a multi-carrier system. An SCMA codeword is a multi-dimensional constellation vector. A codeword can be assigned to multiple UEs and overlapped non-orthogonally in a sparse spreading way. The receiver performs joint multi-user detection for data recovering. An overview of SCMA system design and detailed performance analysis can be found in [7]. A conceptual system block diagram is also provided here in Fig. 4 for reader reference and illustration purpose.

It is seen that the SCMA has special properties compared with the OFDMA-based multiple access. First of all, it is non-orthogonal multiple access. Multiple modulation symbols from different users are superposed on a RE to achieve multiplexing gain. For example, in Fig. 4, on subcarrier 1, symbols from UE1, 3, and 5 are overlapped. Due to the non-orthogonal nature, SCMA system is expected to be able to accommodate more users than orthogonal systems. For example, Fig. 4 demonstrates a case where 6 users are supported with a spreading length of 4, resulting in an overloading factor of 150%.

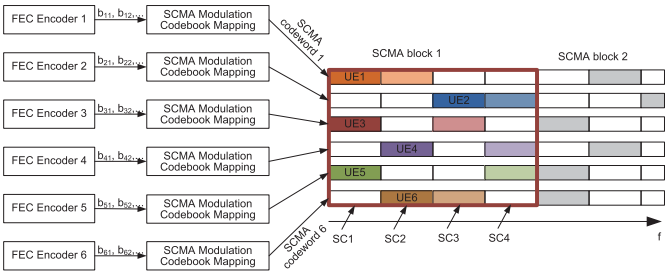


Fig. 4. Conceptual overview of SCMA system.

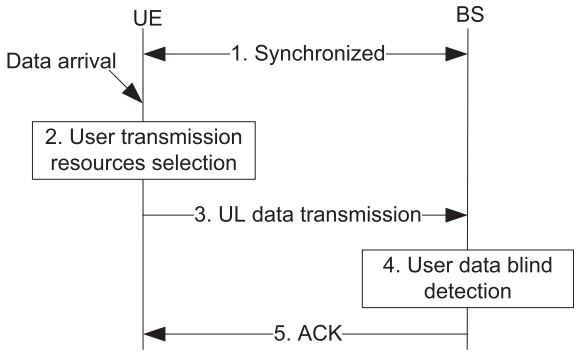


Fig. 5. SCMA-based UL grant-free transmission procedure.

Higher overloading can be achieved by many ways including but not limited to reusing the layers and/or enlarging the spreading factor. Secondly, the frequency domain spreading enhances the detection robustness to channel variation and user mobility. It is also good for coverage improvement. Thirdly, the sparse spreading design in the SCMA codebook helps to limit the total interference on each RE to enables the application of moderate complexity multiuser detection based on the idea of message passing algorithm (MPA) [14] [15] with close to maximum likelihood detection performance. Finally, instead of linear spreading in which each constellation on the non-zero tone is simply repetition, SCMA allows constellation reshaping and relabel among the non-zero tones, which brings further coding gain and higher spectrum efficiency compared with linear spreading.

C. SCMA-Based UL Grant-Free Transmission Design

An SCMA-based UL grant-free transmission flowchart is presented in Fig. 5, where time synchronization is assumed maintained between the UE and the network. This could be easily realized for a UE in RRC Connected state. For a UE in ECO state, large cyclic prefix (CP) value can be applied for dense small cell coverage to accommodate different propagation delay. For macro cell coverage, ECO UEs can also make time advance (TA) adaption based on DL measurement. At data arrival, UE selects the transmission resources appropriately and directly sends out the UL data at transmission opportunity. The base station blindly detects the UE identity and the carried UL data and feedback an ACK/NACK for transmission confirmation. Possible retransmission can be conducted the same way as new transmission to achieve combining gain.

In order to support SCMA-based UL grant-free transmission, radio resource pool is a priori to UEs, which may include the combination of time, frequency, SCMA codebooks, and pilot sequences. Time and frequency resource is referred to as physical resource while SCMA codebooks and pilot sequences are multiple access (MA) signatures. For one particular transmission, both the physical resource and MA signatures can be preconfigured by base station or randomly selected by the UEs from the pool.

In our test, we fix the physical resource while allow the UEs to randomly select a pilot and a codebook for each UL transmission. In order to facilitate the blind detection at the network side, a one-to-one mapping or a many-to-one mapping between the pilot sequences and codebooks is predefined and known to both UE and network sides. It is possible that several UEs may choose the same codebook since the number of pilot sequences can be larger than the number of codebooks. In this case, however, as each codebook goes through different wireless channel, the MPA receiver is still able to detect the data as long as different pilot sequences are used. It is verified in [7] that the performance loss due to codebook collision is less than 0.5dB which is negligible for a real system. However, if UEs choose the identical pilot sequence, the receiver cannot differentiate the channels of different UEs and therefore cannot decode the data, which is called pilot collision. To alleviate pilot collision, the number of pilot sequence needs to be large enough for UEs to select randomly. Assume a Poisson distributed traffic model with average packet arrival rate of λ packets per transmission time interval (TTI) from massive UEs. The probability of n packets arrival (same as n active users) follows Poisson distribution:

$$P(X = n) = \lambda^n e^{-n}/n!, n = 0, 1, 2, ...\lambda > 0.$$

With a total of n active UEs and M pilot sequences, the pilot collision probability is formulated as

$$p(n) = \begin{cases} 1 - \frac{M(M-1)(M-2)\cdots(M-n+1)}{M^n} & n \leq M \\ 1 & n > M. \end{cases}$$

It is assumed that all packets using the same pilot sequence will be failed if there is a pilot collision. The upper-bounded packet loss rate as a function of λ is estimated by

$$P(\lambda) = \sum_{n=0}^{\infty} P(X = n) p(n) \frac{n}{\lambda}.$$

Collision problem may be further resolved by applying random backoff during retransmissions.

In this prototype, 2 ZC root sequences are used and each can be phase shifted to generate 12 orthogonal pilot sequences. The total 24 pilot sequences are divided into two groups which are associated with different symbols in time domain. To mitigate interference, pilot sequences in each group are also separately mapped as shown in Fig. 6, where pilot sequences from group 1 are mapped to resource elements in symbols 2 and 9 while those from group 2 are mapped to symbols 3 and 10 in a subframe.

It is noted that each UE can randomly select a pilot sequence and then a codebook. An SCMA encoder diagram with simplified functional blocks at transmitter is shown in Fig. 7.

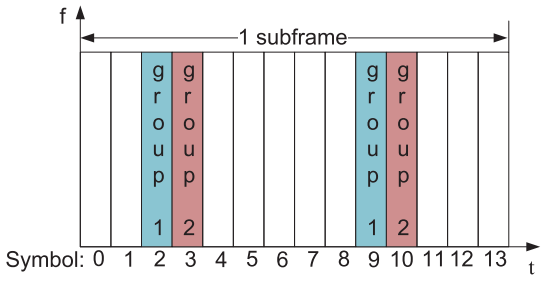


Fig. 6. Pilot sequence mapping.

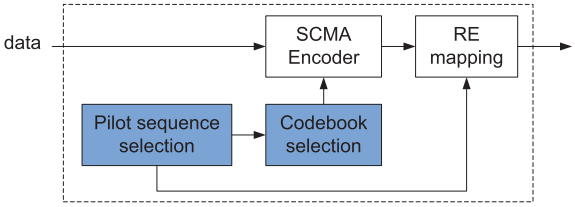


Fig. 7. SCMA encoder at transmitter.

TABLE I
CODEBOOK AND PILOT SEQUENCE MAPPING TABLE

Codebook	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
Pilot seq. group 1 (No.1–12)	$P_{1,1}$	$P_{1,2}$	$P_{1,3}$	$P_{1,4}$	$P_{1,5}$	$P_{1,6}$	$P_{1,7}$	$P_{1,8}$	$P_{1,9}$	$P_{1,10}$	$P_{1,11}$	$P_{1,12}$
Pilot seq. group 2 (No.13–24)	$P_{2,1}$	$P_{2,2}$	$P_{2,3}$	$P_{2,4}$	$P_{2,5}$	$P_{2,6}$	$P_{2,7}$	$P_{2,8}$	$P_{2,9}$	$P_{2,10}$	$P_{2,11}$	$P_{2,12}$

The receiver blindly detects the uplink packets and the UE activity by attempting reception using all possible pilot sequences and codebooks. As mentioned above, pilot sequence and codebook can be designed to have a one-to-one or many-to-one mapping relation. In this case, once the pilot sequence is blindly detected at the receiver, the codebook is determined which can increase the detection efficiency for real time processing. In a many-to-one mapping, codebook can be potentially reused by more than one UE. A two-to-one pilot sequence to codebook mapping table can be designed as shown in Table I.

IV. LAB TESTING ON UL GRANT-FREE TRANSMISSION IN UCNC

A. Lab Testing Setup

The world's first PoC on 5G UCNC RAN architecture is deployed and tested in the 5G Joint Innovation Lab in Madrid, Spain. The prototype logical architecture is shown in Fig. 8, where three TRPs are deployed for three cells. UEs are randomly distributed under the coverage of the three TRPs. The base band unit (BBU) implements centralized baseband signal processing. Joint reception is conducted where the signal from the best TRP is used for user data packet detection. The mobile cloud engine (MCE) is used as a controller and coordinator for system control. The testing results are output to the user interface (UI) server for demonstration.

Accordingly the testbed in lab is shown in Fig. 9.

It is noted that the MCE and the BBU are collocated and implemented in a commercial server. BBU is responsible

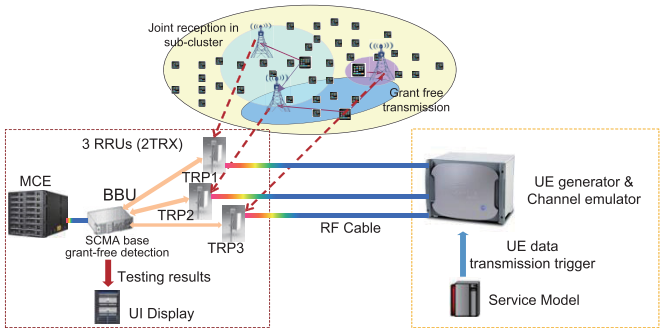


Fig. 8. Prototype architecture.

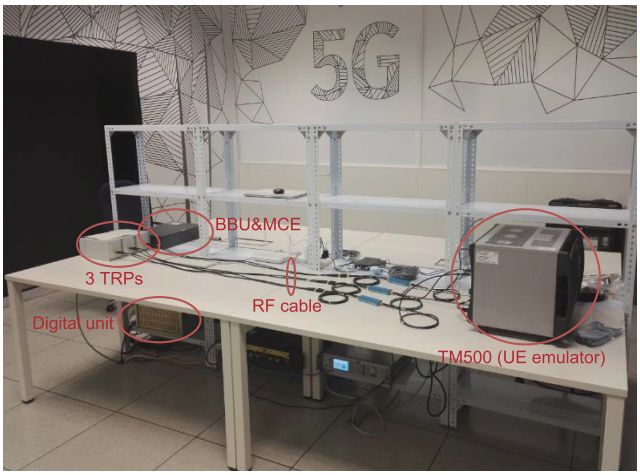


Fig. 9. Hardware setup in lab.

for physical layer baseband processing, such as channel coding, modulation, waveform generation and shaping, resource mapping and etc. The cloud baseband is software-based and implemented in C/C++ language. The TRPs integrate both radio frequency (RF) unit and intermediate frequency (IF) unit. The main function of IF unit is digital-to-analog (DA) and analog-to-digital (AD) conversion. Also power amplification is implemented to compensate for power loss. The RF unit consists of local oscillator, mixer and power amplifier to convert the IF signal to RF signal and vise versa. Direct connection between the TRPs and the BBU server is not possible because the I/O signal of TRP is standard common public radio interface (CPRI) signal while the server is configured with network interface card (NIC) for Ethernet connection. An additional digital unit is introduced to conduct signal conversions between the digital CPRI baseband signals and the 10GBASE Ethernet signal. In addition, the digital unit also serves as a master clock to manage time and frequency synchronization among BBU and TRPs. In lab testing, the air interface is not open and RF cables are used to carry radio signals between the UEs and the TRPs. Due to the lack of massive 5G low cost devices for testing, a commercial UE and traffic generator, Cobham TM500, is used to emulate massive UEs. Furthermore, TM500 can also emulate different radio channel models.

The detailed air interface specification is shown in Table II.

TABLE II
AIR INTERFACE SPECIFICATION

Configuration Item	Values
Operating band	2.35GHz
System BW	20MHz
Subcarrier BW	15KHz
Available data BW	1.44MHz/8PRB
TRP number	3
TRP TRx number	2T2R
UE TRx number	1T2R
TTI length	1ms
Frame structure	TDD configuration 1
CP length	Long CP:5.2us(160 samples) Short CP:4.69us(144 samples)
SCMA code rate	0.67
SCMA codebook	24-by-8
REs per SCMA block	8
Layers/UE	2
Modulation	QPSK
DL reference signal	CRS
UL reference signal	DMRS
Channel model	AWGN

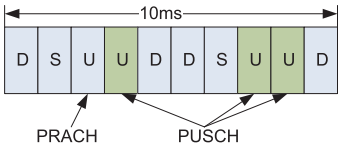


Fig. 10. Frame structure.

In a subframe with 14 symbols, it is designed that only 10 symbols in a contention-based transmission units (CBTU) are used for data transmission and the first 4 symbols are used for control signaling. A SCMA code rate of 0.67 is achieved by taking into account the number of REs in each SCMA block and the number of layers supported. Due to the lack of channel status information before data transmission, robust QPSK modulation is applied for all UEs. With TDD configuration 1 of UL: DL=1:1, totally four UL subframes are configured in a 10ms frame structure. However, only three grant-free transmission opportunities are provided in the 3rd, 7th and 8th subframe respectively and the 2nd subframe contains a PRACH channel used for random access as shown in Fig. 10.

A UE follows Poisson process to generate data packets and the average packet arrival interval is set to 300s. A packet consists of 17B payload and 3B CRC which makes a 20B transport block (TB). No retransmission is implemented at present. However, transmission diversity is applied where each 20B TB is transmitted over two CBTUs independently. Each CBTU consists of 4 PRBs as shown in Fig. 11. This means independent pilot sequence and codebook selection in two transmissions. A much reliable user access is achieved as packet loss happens only when the two transmissions are all failed.

Joint reception is implemented with three TRPs. The receiver makes combining to achieve higher detection rate probability. We design a 90% packet detection rate for each independent transmission, which results in a system packet detection rate of 99%.

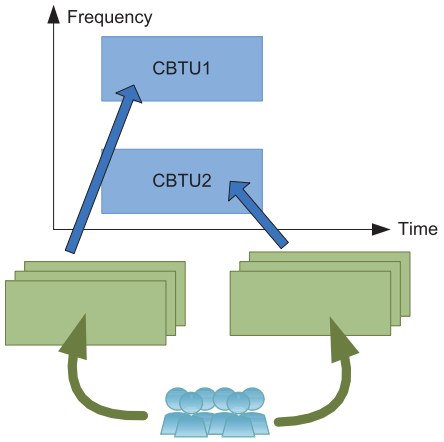


Fig. 11. Transmission diversity.

B. Lab Testing Results

Three test cases are developed to investigate the performance matrices in terms of signaling and latency reduction and massive connectivity support. There are listed as:

- Test case 1: SCMA-based UL grant-free transmission;
- Test case 2: Fast system re-entry; and
- Test case 3: Joint UL reception with massive UE support.

The detailed testing setups, procedures and results will be elaborated in the following subsection.

1) Test Case 1: SCMA-Based UL Grant-Free Transmission: The main objective of this test is to investigate UL grant-free transmission in RRC Connected state. Grant-free transmission is expected to reduce the scheduling signaling overhead and thereafter the power consumption on signaling processing. Two performance matrices are studied:

- Control signaling overhead;
- CPU usage for signaling processing.

The operation procedure is as follows:

1) Power on and initialize digital unit, TRPs, BBU and MEC and UEs;
2) UE obtains time/frequency synchronization with BBU;
3) UE enters RRC Connected state and ready for data transmission;
4) UE generates small data packets according to the service model;
5) UE waits for UL transmission opportunity and transmits data packet without scheduling procedure;
6) BBU blindly detects UE grant-free transmission;
7) BBU periodically sends accumulated number of signaling and CPU usage to display.

Totally 150,000 UEs are distributed uniformly in the coverage of 3 TRPs with a ratio of 1:1:1 and 1:2:1, respectively. AWGN channel model is emulated by TM500 and the maximum path loss values between cell center and cell edge UEs are set to within 36.75dB and 28.75dB, respectively. Scheduling procedure in LTE is used as a baseline for comparison purpose. Fig. 12 shows a snapshot of the UI display for test case 1 where the UE distribution is shown. The signaling procedures for UL transmission in LTE and UCNC are demonstrated and the number of signaling is accumulated

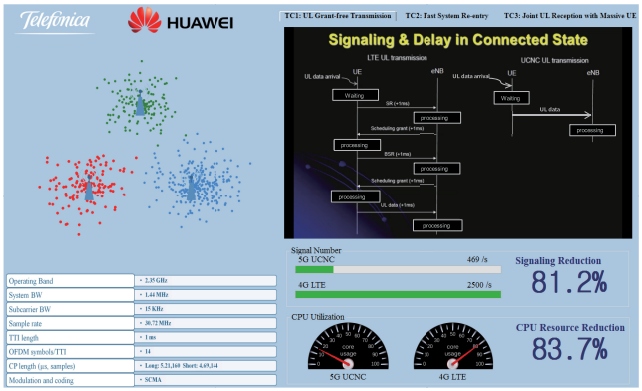


Fig. 12. Snapshot of UI display for test case 1.

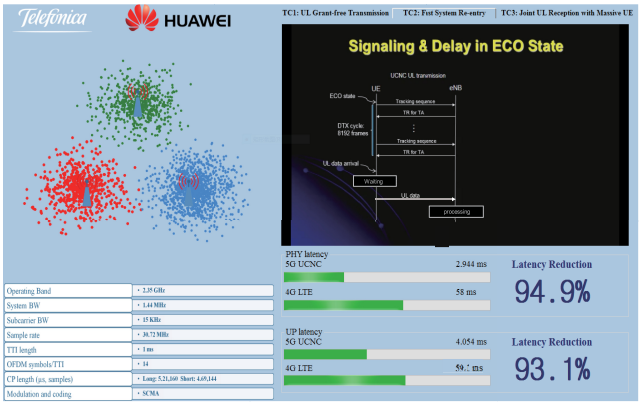


Fig. 13. Snapshot of UI display for test case 2.

TABLE III
SIGNALING REDUCTION AND CPU UTILIZATION REDUCTION

UE distr.	Path loss diff. (dB)	signaling per second	signaling reduction	CPU utilization	CPU uti. reduction
1:1:1	36.75	400–600	80%	12–18%	80%
	28.75	400–600	80%	12–18%	80%
1:2:1	36.75	400–600	80%	12–18%	80%
	28.75	400–600	80%	12–18%	80%

and updated in each second. Accordingly the CPU usage percentage for signaling processing is also compared between the UCNC and LTE schemes. Strictly speaking, UEs applying grant-free transmissions can send out data packet directly at transmission opportunity without any signaling overhead. Here we include the data transmission procedure as one signaling so as to compute the performance gain.

The detailed statistical results are shown in the following Table III. From the table, it is seen that the number of signaling over air is changing between 400∼600 with an average of 500 per second for UCNC. For request-grant based scheduling procedure in LTE, the results are not shown in the table due to the space limit, but the accumulated number of signaling over air is changing between 2000∼3000 with an average of 2500 per second. The signaling overhead with UCNC can be reduced by up to 80% in average compared to LTE. The percentage of CPU usage for signaling processing with UCNC is also shown in Table III. It is between 12%∼18% with an average of 15%. Compared to LTE scheme, the CPU utilization efficiency can also be improved by up to 80% in average due to the significantly reduced scheduling signaling process. Due to the centralized coordination and processing in UCNC, different UE distribution has no effect on performance matrix. This conclusion can also be observed in the following test cases. This feature can effectively accommodate unbalanced traffic load in a hyper-cell as well as improve energy/cost efficiency [16]. The testing results also verify that at heavy traffic load, scheduling signaling will dominate the signaling overhead, the CPU utilization and power consumption. In this sense, grant-free transmission seems to be a promising solution in supporting the ever increasing wireless connections with small data packet services.

2) Test Case 2: Fast System Re-Entry: This test is to study UL grant-free transmission in ECO state. After the UE gets synchronized to the BBU and enters RRC Connected state, it will further be switched to ECO state. Because UEs in ECO state can conduct UL grant-free transmission without state transition to RRC Connected state, fast system re-entry is achieved. The performance matrix to be evaluated is transmission latency. Two types of transmission delay are defined and evaluated:

PHY delay: For LTE system, it is defined as the time elapsed from the initiation of random access procedure at UE side to the reception of the first data packet at physical layer at BBU side; For UCNC system, it is defined as the time elapse from the availability of data packet at physical layer at the UE side to the reception of the data packet at the physical layer at the BBU side;

User plane (UP) delay: time spent from the availability of data packet at IP layer at the UE side to the reception of the data packet at the IP layer at BBU side.

Fig. 13 gives a snap shot of the UI display for test case 2. The UE tracking procedure is shown for TRP association in ECO state. Grant-free transmission in ECO state is also demonstrated. Both the real-time measured PHY and UP latency are shown and compared with LTE scheme. Because grant-free transmission in ECO state will not go through all the preparation procedures for data path establishment, significant performance gain in terms of transmission latency can be achieved as shown in Fig. 13.

Extensive testing results with different parameters are given in Table IV. Traffic load variation is captured as the number of UEs distributed in the system can choose between 450,000 and 600,000, respectively. It is seen that the UCNC scheme can achieve PHY and UP latency at around 3ms and 4ms, respectively in all scenarios. However, for LTE system with the assumption that signaling transmission and processing in backhaul only takes 10ms, average PHY and UP transmission delays of 58ms and 59.1ms are still needed. Take these numbers as baseline in comparison, the PHY and UP latency in UCNC can outperforms that in LTE by around 95% and 93%, respectively.

3) Test Case 3: Joint UL Reception With Massive UE Support: This test case is designed to investigate the capability

TABLE IV
TRANSMISSION LATENCY REDUCTION

UE distri.	Pkt. arr. interval (s)	no. of UEs	Path loss diff.(dB)	PHY Latency (ms)	PHY Latency reduction	UP Latency (ms)	UP Latency reduction
1:1:1	300	450,000	36.75	2.89–2.95	94.9–95.0%	3.99–4.02	93.6–93.7%
			28.75	2.89–3.01	94.8–95.0%	3.99–4.05	93.6–93.7%
1:1:1	300	600,000	36.75	2.97–3.03	94.7–94.9%	4.02–4.12	93.5–93.6%
			28.75	2.95–3.05	94.7–94.9%	4.03–4.14	93.4–93.6%
1:2:1	300	450,000	36.75	2.87–3.00	94.8–95.0%	3.99–4.12	93.5–93.7%
			28.75	2.90–3.04	94.8–95.0%	4.00–4.14	93.4–93.7%
1:2:1	300	600,000	36.75	2.99–3.04	94.8–94.9%	4.04–4.16	93.4–93.6%
			28.75	2.98–3.10	94.7–94.9%	4.03–4.20	93.3–93.6%

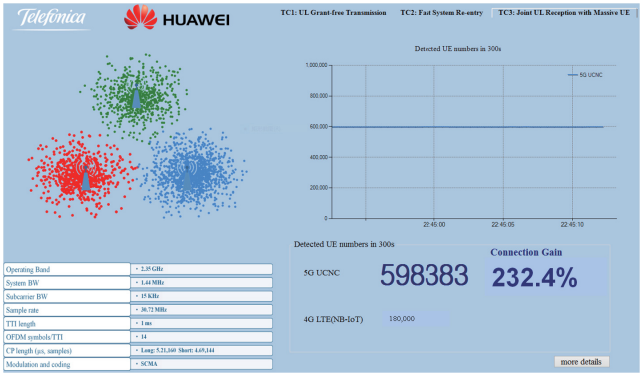


Fig. 14. Snapshot of UI display for test case 3.

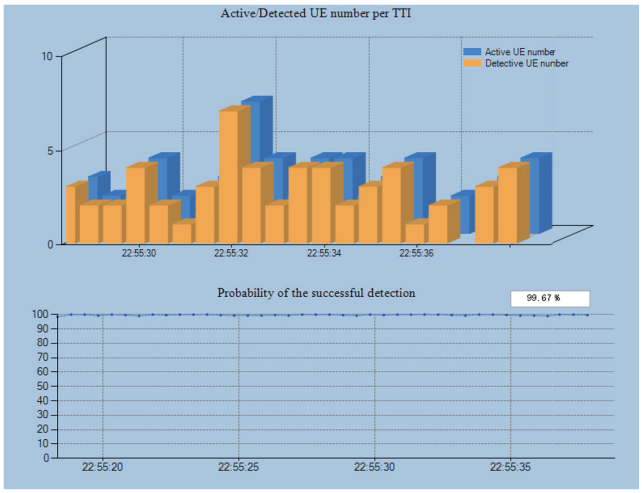


Fig. 15. Detected number of UEs in a subframe and packet detection rate.

of massive connectivity support and the SCMA performance with joint detection by 3 TRPs.

Fig. 14 gives a snapshot of the UI display for this test where the number of simultaneously supported UEs by using SCMA multiple access scheme is provided. The number of UEs supported by using orthogonal OFDMA scheme is also given. For comparison fairness, the testing parameters, including the radio resource block size, the modulation scheme and etc., are all set to the same values. Due to preconfigured resource size and orthogonal resource allocation, the OFDMA can support a fixed number of 180,000 UEs while the UCNC can support around 600,000 UEs simultaneously.

Fig. 15 gives the average number of active UEs and detected UEs in each subframe during some testing interval. It is shown that almost all the data packets are detected successfully. This observation is further verified with a detection rate of 99.67% which fulfill the design goal of 99% packet detection rate.

TABLE V
MASSIVE UES SUPPORT AND PACKET DETECTION RATE

UE distri.	Pkt. arr. interval (s)	no. of UEs	Path loss diff. (dB)	No. of connections	Connection gain	Max. det. UEs/SF
1:1:1	300	450,000	36.75	447,000	148.3%	8
			28.75	450,000	150.0%	8
1:1:1	300	600,000	36.75	595,000	230.6%	10
			28.75	600,000	233.3%	10
1:2:1	300	450,000	36.75	449,000	149.4%	8
			28.75	450,000	150.0%	8
1:2:1	300	600,000	36.75	597,000	231.7%	10
			28.75	598,000	232.2.0%	10

The detailed testing results are summarized in Table V. The number of supported connections is accumulated at various UE densities. It is seen that SCMA multiple access scheme can greatly outperforms the OFDMA scheme by supporting much more connections. In a system with medium traffic load, for instance 450,000 UEs with a packet interval arrival time of 300s, a gain of 150% can be achieved. When the number of UEs is increased to 600,000, around 230% gain can be achieved at the cost of increased packet loss rate of 2%. The maximum number of detected UEs in a subframe is also given in the table.

V. CONCLUSION REMARKS

In this paper, an overview on the proposed UCNC RAN architecture and some key technologies are presented. UCNC is a promising candidate in 5G network architecture design to achieve user centric communication for constant user experience provisioning. In addition, signaling overhead reduction not only can achieve reduced transmission latency, but also make efficient power consumption. Phase I PoC of UCNC studies the validity and efficiency of SCMA-based UL grant-free transmission. Performance matrices in terms of signaling overhead and CPU utilization, transmission latency and the massive connections capability are investigated for the first time in a practical communication environment. Testing results demonstrate that SCMA-based UL grant-free transmission can significantly outperforms the OFDMA-based scheduling transmission. It is shown that grant-free transmission can reduce signaling overhead by around 80%. When the scheme is used in ECO state, the user plane transmission latency can be reduced by around 93% which is appealing for delay sensitive application support in future 5G networks. Massive connectivity with a large number of UEs can be simultaneously supported with the SCMA multiple access scheme, which can achieve around 230% gain compared to the OFDMA scheme. Therefore, the SCMA-based UL grant-free scheme can be a promising technology for 5G wireless networks for data transmission with low signaling overhead, low latency, and efficient support of massive connectivity. Field trial is ongoing where the air interface will be open and the effect of realistic radio channel on performance will be evaluated. Furthermore, user mobility will also be introduced.

For the upcoming phase II PoC, the testbed will have coordinated transmission and reception and handoff schemes integrated with the focus on user centric and no cell concept verification. More TRPs will be deployed in the field trial and constant user experience will be provided with 100Mbps data transmission rate anywhere. UL measurement based TRP selection and association will be developed and close coordination among TRPs with newly designed transmission and reception algorithms will be evaluated for mobile UEs. 0ms handoff interruption time can also be expected for mobile UEs. The testing results will be presented in the upcoming papers.

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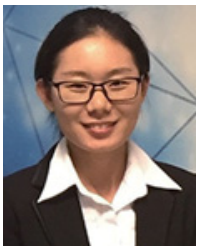
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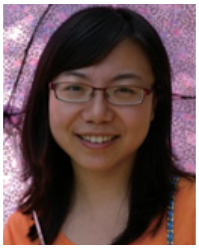
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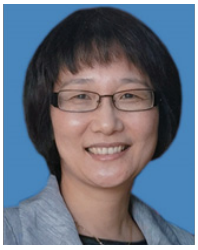
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