LTE-Advanced in 3GPP Rel-13/14: An Evolution Toward 5G

While 5G will integrate the latest technology breakthroughs to achieve the best possible performance, it is expected that LTE-Advanced will continue to evolve, as a part of 5G technologies, in a backward compatible manner to maximize the benefit from the massive economies of scale established around the 3rd Generation Partnership Project LTE/LTE-Advanced ecosystem from Release 8 to Release 12.

Juho Lee, Younsun Kim, Yongjun Kwak, Jianzhong Zhang, Aris Papasakellariou, Thomas Novlan, Chengjun Sun, and Yingyang Li

The authors are with Samsung Electronics.

Abstract

As the fourth generation (4G) LTE-Advanced network becomes a commercial success, technologies for beyond 4G and 5G are being actively investigated from the research perspective as well as from the standardization perspective. While 5G will integrate the latest technology breakthroughs to achieve the best possible performance, it is expected that LTE-Advanced will continue to evolve, as a part of 5G technologies, in a backward compatible manner to maximize the benefit from the massive economies of scale established around the 3rd Generation Partnership Project (3GPP) LTE/LTE-Advanced ecosystem from Release 8 to Release 12. In this article we introduce a set of key technologies expected for 3GPP Release 13 and 14 with a focus on air interface aspects, as part of the continued evolution of LTE-Advanced and as a bridge from 4G to 5G.

Introduction

The wireless cellular network has been one of the most successful communications technologies of the last three decades. The advent of smartphones and tablets over the past several years has resulted in an explosive growth of data traffic. With the proliferation of more smart terminals communicating with servers and each other via broadband wireless networks, numerous new applications have also emerged to take advantage of wireless connectivity.

After the introduction of the 4G LTE-Advanced [1, 2] standard in 3GPP Rel-10, LTE-Advanced has continued to evolve through several releases and has become a global commercial success. The research community is now increasingly looking beyond 4G and into future 5G technologies, both in standardization bodies such as 3GPP and in research projects such as the EU FP7 METIS. ITU-R has recently finalized work on the "Vision" for 5G systems, which includes support for explosive growth of data traffic, support for massive numbers of machine type communication (MTC) devices, and support for mission critical and ultra-reliable and low latency communications [3]. While today's commercial 4G LTE-Advanced networks are mostly deployed in legacy cellular bands from 600 MHz to 3.5 GHz, recent technology advancements will allow 5G to utilize spectrum opportunities below 100 GHz, including existing cellular bands, new bands below 6 GHz, and new bands above 6 GHz, including the so-called mmWave bands. There are coordinated efforts across the world to identify these new spectrum opportunities. There were decisions for new spectrums below 6 GHz at the World Radio-communication Conference (WRC)-2015, and further decisions for new spectrums above 6 GHz are expected at WRC-2019.

From the 5G technology roadmap perspective, we expect a dual-track approach to take place over the next few years in 3GPP. The first track is commonly known as the "evolution" track, where we expect the evolution of LTE-Advanced will continue in Rel-13/14 and beyond in a backward compatible manner, with the goal of improving system performance in the bands below 6 GHz. It is also our expectation that at least a part of 5G requirements can be met by the continued evolution of LTE-Advanced. For example, latency reduction with grant-less uplink access and shortened length of a transmission time interval (TTI) can make the over-the-air latency less than 1 ms. The second track is commonly known as the "new RAT" track in 3GPP, which is not limited by backward compatibility requirements and can integrate breakthrough technologies to achieve the best possible performance. The "new RAT" 5G system should meet all 5G requirements as it would eventually need to replace the previous generation systems in the future. The "new RAT" track is also expected to have a scalable design that can seamlessly support both above and below 6 GHz bands.

In this article, we focus on a set of important air interface features of LTE-Advanced in 3GPP Rel-13. We also discuss air interface features that are expected to be specified in 3GPP Rel-14. In the continued evolution of LTE-Advanced in Rel-13 and Rel-14, it is important to emphasize continuity and backward compatibility in order to leverage massive economies of scale associated with the current ecosystem developed around LTE/LTE-Advanced standards from Rel-8 to Rel-12.

Rel-13 includes three major technology categories. The first category is the enhancement of spectral efficiency, and its representative technology is full dimension MIMO (FD-MIMO) that aims to drastically increase spectral efficiency via the use of a large number of antennas at the base station. The second category is the utilization of additional frequency resources and includes licensed assisted access (LAA) for utilizing unlicensed spectrum while guaranteeing coexistence with existing devices and enhanced carrier aggregation (eCA) with up to 32 component carriers. In the third category are the technologies to support new services. A representative example is further cost reductions for MTC devices that can also support extended coverage. Other technologies in this category include enhancement of device-to-device (D2D) proximity services that was specified in Rel-12 for the support of peer discovery as well as direct communication between proximity UEs, indoor positioning enhancements, and single-cell point-to-multipoint (SC-PTM) as a complementary tool for support of enhanced multimedia broadcast and multicast service (eMBMS).

Discussion on the evolution of LTE-Advanced in Rel-14 is already occurring. It is expected that there would be continued evolution of the features introduced in Rel-13, such as FD-MIMO and LAA. It is also expected that Rel-14 would introduce technologies for latency reduction, which is one of the most important aspects for improving the user experience but has not been improved much since the introduction of LTE. Technologies for vehicle-related services (V2X) such as vehicle-to-vehicle (V2V), vehicle-to-infra (V2I), and vehicle-to-pedestrian (V2P) have recently attracted significant attention from the cellular industry as another opportunity for LTE-Advanced technologies to be extended to support vertical industries, and are expected to be specified in Rel-14. As a technology for further improving spectral efficiency by allowing non-orthogonal downlink transmissions within a cell, the enhancement for downlink multiuser transmission using superposition coding was studied during Rel-13 for potential specification work in Rel-14.

The rest of this article is organized as follows. First, we describe FD-MIMO, LAA, and eCA with up to 32 component carriers, which would be the representative features in Rel-13 for improving spectral efficiency and utilizing additional frequency resources. Second, we introduce MTC as a representative example of Rel-13 technologies for support of new services. Third, we describe the features that are expected to be specified in Rel-14. The final section provides concluding remarks.

Full Dimension MIMO

FD-MIMO is one of the key candidate technologies considered for the evolution toward beyond 4th generation (B4G) and 5th generation (5G) cellular systems. The key idea behind FD-MIMO is to utilize a large number of antennas placed in a two-dimensional (2-D) antenna array panel to form narrow beams in both the horizontal and vertical directions. Such beamforming allows the enhanced NodeBs (eNB: 3GPP terminology for base station) to simultaneously transmit to multiple user equipments (UE: 3GPP terminology for mobile station) to realize high order multi-user spatial multiplexing.

Figure 1 depicts an eNB with FD-MIMO implemented using a 2-D antenna array panel, where every antenna is an active element allowing dynamic and adaptive precoding across all antennas. By utilizing such precoding, the eNB can simultaneously direct transmissions in the azimuth and elevation domains for multiple UEs. The key feature of FD-MIMO in improving the system performance is its ability to realize high order multi-user multiplexing.

3GPP has conducted several studies since December 2012 in an effort to provide specification support for FD-MIMO. The first step was a study item [4] for developing a new channel model for future evaluation of antenna technologies based on 2-D antenna array panels. The channel model provides the stochastic characteristics of a three-dimensional (3-D) wireless channel. Based on the new channel model, a follow-up study item [5] on FD-MIMO was initiated in September 2014 to evaluate the performance benefits of standard enhancements targeting the 2-D antenna array operation with up to 64 antenna ports over a standard-transparent approach such as vertical sectorization utilizing antenna elements in the vertical direction.

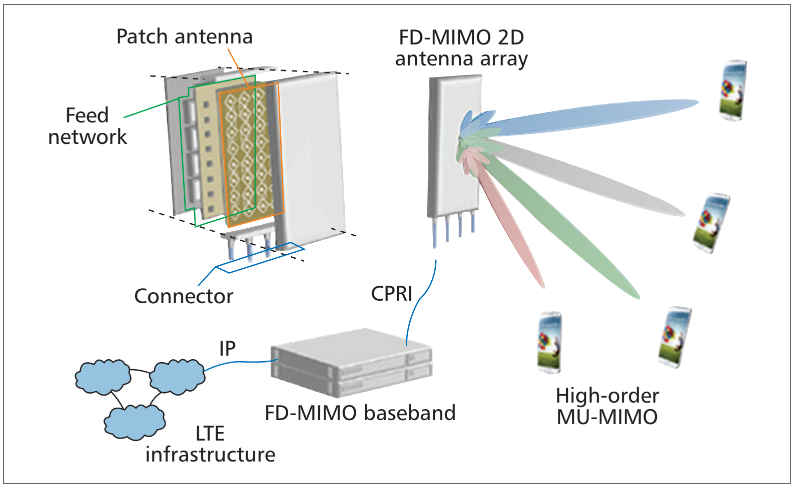

Figure 1. Conceptual diagram of a FD-MIMO system realizing high order MU-MIMO through a 2-D antenna array.

FD-MIMO has two important differentiating factors compared to MIMO technologies from previous LTE releases. First, the number of antennas can be increased beyond eight, e.g. to 64. As a result, FD-MIMO significantly improves beamforming and spatial user multiplexing capability. Second, specification support for FD-MIMO is targeted for antennas placed on a 2-D planar array. Using the 2D planar placement is also helpful in reducing the form factor of the antennas for practical applications.

Figure 2 summarizes the cell average throughput of FD-MIMO for various eNB antenna configurations (left) and various numbers of UEs per cell (right), where all UEs are distributed on the same horizontal plane, i.e. without UE distribution along the vertical direction. More details can be found in [6]. The antenna configuration is determined by the number of transmit antennas (N_T) and the 2-D antenna placement ($N_H \times N_V$) where N_H and N_V are the number of antennas on the horizontal and vertical directions, respectively.

The performance of MIMO utilizing up to eight transmit antennas was evaluated to be around 2.8 bps/Hz for cell average throughput and 0.1 bps/Hz for 5 percent-tile user throughput (cell edge performance) when there were 10 UEs per cell. Compared to these values, Fig. 2 (left) shows dramatic performance enhancements for FD-MIMO of up to 400 percent or more for both cell average throughput and 5 percent-tile user throughput. Additionally, Fig. 2 shows that although a one-dimensional horizontal antenna array provides the best performance, FD-MIMO with 2-D arrays also provides significant performance improvement while allowing for practical implementations.

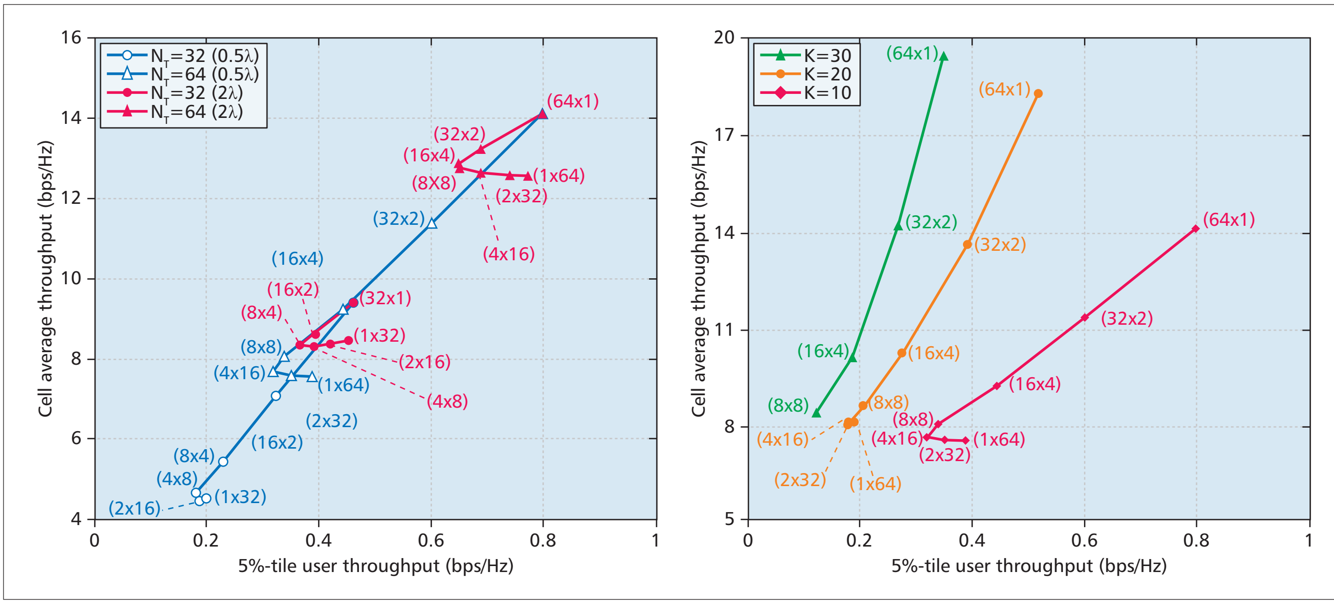

Figure 2. FD-MIMO cell average throughput for various antenna configurations (left) and various numbers of UEs in a cell (right).

Figure 2 (right) shows the cell average throughput for $N_T = 64$ antennas and for 10, 20, and 30 UEs per cell. It was assumed that the eNB transmits spatially multiplexed signals to all UEs in the cell. The results show that as the number of UEs per cell increases, the cell throughput of FD-MIMO also increases due to the associated increase in the order of multi-user spatial multiplexing.

Taking into account the significant performance benefit observed in the feasibility study and the available time for the specification work, LTE-Advanced in Rel-13 specified support for FD-MIMO with up to 16 transmit antenna ports at the eNB. The following enhancements were specified in Rel-13:

- Enhancement of downlink reference signals for measurements from a larger number of antennas on a 2-D array panel.
- Enhancement of channel state information (CSI) such as CSI reporting mechanism and codebook for spatial beamforming in both horizontal and vertical directions.
- Enhancement of demodulation reference signals to enable high order multi-user multiplexing.

FD-MIMO is expected to bring significant performance enhancements to future generations of cellular networks due to the wide range of deployment environments. FD-MIMO can be deployed not only for outdoor macro cells but also for smaller cells such as indoor, micro, and pico cells. Additionally, considering that the antenna spacing is inversely proportional to the carrier frequency, FD-MIMO systems can be deployed with smaller form factors for higher frequency bands.

Licensed-Assisted Access Using LTE

Due to the sharply increased demand for wireless broadband data, the use of unlicensed spectrum is now being considered as a potential complement to LTE systems operating in licensed spectrum. Although licensed spectrum affords operators exclusive control for providing guaranteed QoS and mobility, available bandwidths are typically limited and can be very costly to obtain. In particular, the 5 GHz unlicensed band has attracted considerable interest for LTE deployments due to the potentially large amount of globally available spectrum (>400 MHz). However, LTE operation in unlicensed spectrum needs to coexist with the operation of other radio access technologies (RATs), such as Wi-Fi, and this leads to unique design challenges compared to LTE operation in licensed bands. In June 2015, 3GPP completed the study on licensed-assisted access to investigate and identify possible designs to allow LTE to coexist with Wi-Fi in unlicensed bands [7], and started a work item for specification support.

In Rel-13, only downlink transmissions using the unlicensed band were specified, and the principle of uplink channel access and the necessary forward compatibility mechanism were developed so that the uplink transmission can be added in future releases without modifications to the downlink design. LAA operation in Rel-13 uses carrier aggregation to tightly integrate licensed spectrum and unlicensed spectrum. The primary cell (PCell) is maintained on licensed spectrum to provide control, system information, and continuity for high-QoS services, since unlicensed carriers are likely to be only intermittently available in order to satisfy the coexistence requirement of LAA with other RATs. The main deployment scenarios targeted by the LAA in Rel-13 include outdoor and indoor small cell deployments, with and without the presence of macro cell coverage, and with licensed and unlicensed carriers collocated in the same box.

3GPP intends to define a single global solution framework ensuring that LAA can meet regulatory requirements for all different regions and can co-exist among operators or with other RATs operating on the same band. As a result, a major focus of the work in 3GPP was to perform extensive evaluations for the LAA design

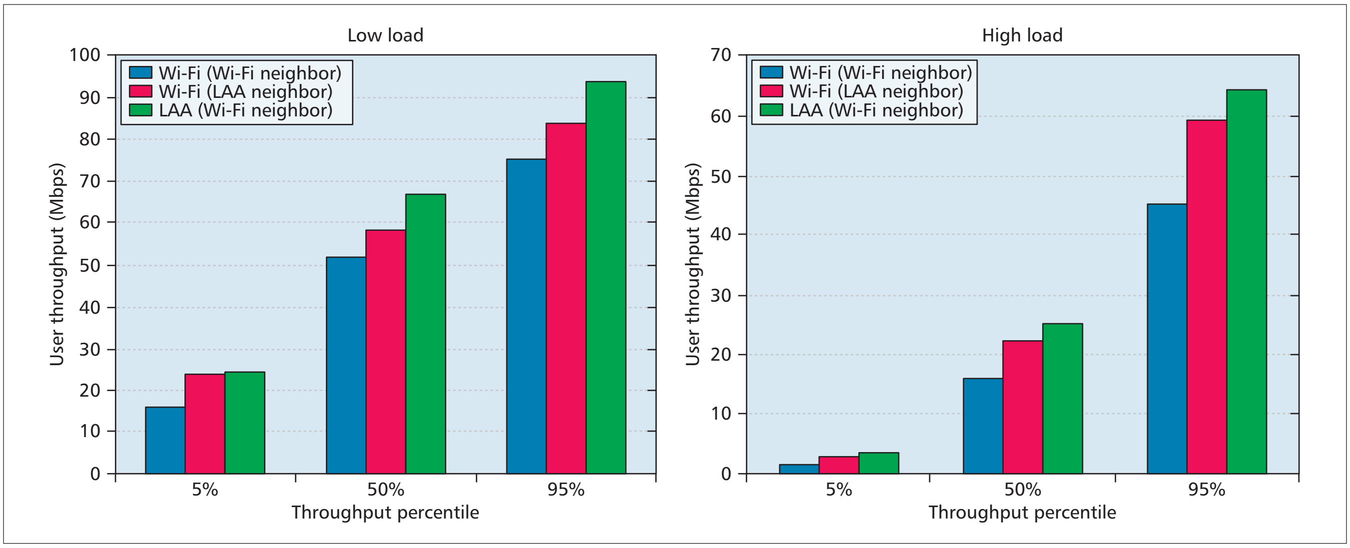

Figure 3. User throughput for coexisting Wi-Fi and LAA networks for low and high traffic loads (results from [6]), of which detailed simulation assumptions can be found in section A.1 of [6].

functionalities that ensure fair coexistence with Wi-Fi deployments. For example, one can consider a typical Wi-Fi network with two different Wi-Fi nodes. If one of them is replaced by a hypothetical LAA node, it should be ensured that the throughput and latency of the remaining Wi-Fi node should not be negatively impacted relative to the original Wi-Fi/Wi-Fi setup. Likewise, coexistence evaluations were also carried out for multi-operator LAA scenarios, since coordination and synchronization between nodes belonging to different operators cannot be universally assumed.

One key mechanism for enabling LAA/Wi-Fi and multi-operator LAA coexistence is listen-before-talk (LBT). LBT governs when a LAA cell may access the channel. For example, according to the European regulations in [8] for load-based equipment, clear channel assessment (CCA) must be performed prior to starting a new transmission. An extended CCA is performed if the medium is determined to be occupied during the CCA and transmission is postponed until the channel is considered clear. An LBT mechanism is expected to be a major part of the specification support for LAA. The intermittent nature of LAA transmissions also has significant implications on existing LTE functionalities such as radio resource management (RRM) measurements, automatic gain control (AGC) settings, coarse and fine time/frequency synchronization, and CSI measurements. Further, support for uplink operation on unlicensed spectrum requires careful study of the resource allocation and feedback mechanisms that may be impacted due to their current reliance on synchronized and fixed timelines.

Due to its capability to aggregate traffic across both licensed and unlicensed bands, and due to its advanced link management techniques, LAA is expected to improve the utilization efficiency of unlicensed spectrum. Consequently, LAA can also benefit other RATs by providing more opportunities for channel access. Based on the evaluation methodology defined in the 3GPP study item [7], Fig. 3 shows user throughput at low and high traffic loads when two neighboring Wi-Fi networks, each of which has four Wi-Fi nodes deployed on a single floor of 120 m x 50 m, coexist on a single unlicensed carrier, and when one operator's Wi-Fi nodes are replaced with LAA nodes.

Although the traffic and user densities of both networks are the same, the network utilizing LAA achieves significant gain in user-perceived throughput, due in part to fundamental LTE capabilities such as link adaptation based on explicit UE feedback and Hybrid ARQ (HARQ). It is additionally observed from Fig. 3 that LAA is a better neighbor to the remaining Wi-Fi network than the previous Wi-Fi network it replaced. This is because a more efficient packet transmission, combined with an adaptive channel utilization mechanism such as LBT, provides increased opportunities for networks coexisting with LAA to access the channel without contention. These benefits also extend to the case where LAA networks of different operators coexist as well. More evaluation results can be found in [7].

Carrier Aggregation Enhancements

As a natural approach for increasing the peak rate and improving the utilization efficiency of distributed frequency resources, carrier aggregation of up to five component carriers with common FDD or TDD duplexing was specified in Rel-10 to support a maximum combined bandwidth of 100 MHz. The combination of carrier aggregation and MIMO provides 3 Gb/s and 1.5 Gb/s peak rate on the downlink and the uplink, respectively. In Rel-12, carrier aggregation was extended to support aggregation of FDD carriers and TDD carriers, but the constraint of aggregating at most five carriers remained. This constraint limits commercial deployments, particularly considering the availability of the 5 GHz unlicensed band that can provide tens of 20 MHz carriers. Additionally, 3GPP is currently studying UE RF requirements for the introduction of CA with four downlink carriers, and it is expected that commercial needs would soon exceed the Rel-12 limitation of five downlink carriers.

Motivated by the above considerations, a new work item was approved for Rel-13 with the objective to specify CA operation for up to 32 carriers (or cells), which can support a peak rate of 25 Gb/s. The main specification impacts are on uplink control signaling and on the reduction of control channel decoding operations that a UE needs to perform. According to the Rel-12 design principle, the number of control channel decoding operations required for a UE increases almost linearly with the number of scheduling cells the UE can support. Rel-13 CA limits this increase by the eNB, essentially configuring the number of blind decoding operations a UE performs per carrier subject to a respective capability reported by the UE. The amount of uplink control information is increased to support HARQ-ACK information or channel state information for a large number of downlink carriers. Further, a UE can be configured to transmit the uplink control information on a secondary cell (SCell) in addition to the PCell to reduce the control signaling overhead of the PCell.

Machine-Type Communications

Support of machine-type communications through cellular networks is emerging as a significant opportunity for new applications in a networked world where devices, e.g. smart power meters, street lights, cars, home electronics such as refrigerators and TVs, and surveillance cameras, communicate with humans and with each other. LTE offers a proven technology with a large existing ecosystem for MTC UEs, but it is also associated with LTE-specific design challenges primarily due to the requirement on a network to simultaneously support UEs with significantly different capabilities and also support coverage enhancements.

Rel-12 specifications for MTC UEs achieved a cost reduction of approximately 50 percent relative to the lowest category LTE UEs (category 1 LTE UEs), and Rel-13 MTC UEs are expected to achieve an additional 50 percent cost reduction primarily through restrictions in transmission/reception within only six resource blocks (RBs) of a system bandwidth per TTI and a lower power amplifier gain, where the RB bandwidth is 180 kHz [9].

The absence of receiver antenna diversity and the possible reduction in a power amplifier gain can result in significant reductions in coverage even for Rel-13 MTC UEs that do not experience large path-loss. A key design target is to provide up to 15 dB coverage enhancement while minimizing the impact on network spectral efficiency and MTC UE power consumption. Coverage enhancement is mainly achieved by repetitions. In order to reduce the required number of repetitions, other physical layer techniques, such as the use of multiple contiguous TTIs to improve channel estimation accuracy and frequency error correction at the receiver, and frequency hopping to increase the frequency diversity gain, are also specified. Narrowband Internet of things (NB-IoT) is also being specified in Rel-13 as another approach for efficient support of low-throughput (~50 kbps) cellular IoT devices using a very narrow bandwidth of 180 kHz (one RB). NB-IoT can be deployed by refarming the 200 kHz GSM carriers, using a single RB in LTE systems, or using a part of the guard band in LTE systems [10].

Features Being Discussed for Inclusion in Rel-14

It is expected that LTE-Advanced in Rel-14 will continue enhancements on FD-MIMO and LAA. For FD-MIMO, the number of eNB transmit antenna ports may be increased to 32 to support larger arrays, and other enhancements may also be specified, including support for more robust FD-MIMO transmission via open loop operation with reduced feedback overhead. For LAA, the support of uplink transmission in the unlicensed band is expected. The rest of this section focuses on latency reduction, V2X, and downlink multiuser transmission using superposition coding, which are expected to be standardized in Rel-14 following the feasibility studies in Rel-13.

Latency Reduction

Latency is one of the most important performance metrics for evaluating wireless communication systems. LTE provides less than 10 ms user plane air latency, and it is now recognized to be a system that provides lower data latencies than previous generations of mobile radio technologies. However, taking into account various emerging applications, tighter latency requirements need to be met, e.g. 1 ms over-the-air latency is being considered as an important requirement of 5G communication systems. 3GPP has started a study [11] of possible technologies for latency reduction, and we expect that they will be specified in Rel-14.

Uplink data transmission involves a scheduling request (SR) by a UE, a resource grant by an eNB, and data packet transmission by the UE. The request-grant procedure occupies a large portion of the entire latency required for uplink data transmission, especially for the transmission of small size payloads such as TCP/IP ACK/NACK. Introducing a grant-less procedure, i.e. removing the request-grant procedure, would be helpful in achieving low latency for small packets. On the other hand, the request-grant procedure is still useful in serving large packets as it enables highly efficient utilization of the valuable spectrum resource.

Another approach gaining attention is shortening the TTI length. In the current LTE standard, the TTI length is 1 ms and is equal to the duration of a subframe, which consists of two slots and corresponds to 14 OFDM symbols. Reducing the TTI length to one slot, i.e. 0.5 ms, or to one OFDM symbol duration, i.e. 0.07 ms, can be good candidates because they allow easy multiplexing of signals with legacy and reduced TTI lengths. With the reduced TTI length, it would be natural to assume that the UE and eNB processing time can be proportionally reduced due to a smaller amount of data to process.

Figure 4 illustrates latency incurred in the existing procedures, and Table 1 shows the latency reduction gain achieved by a grant-less procedure and TTI shortening. The over-the-air latency is lower than 1 ms for a grant-less procedure with a TTI length of one OFDM symbol.

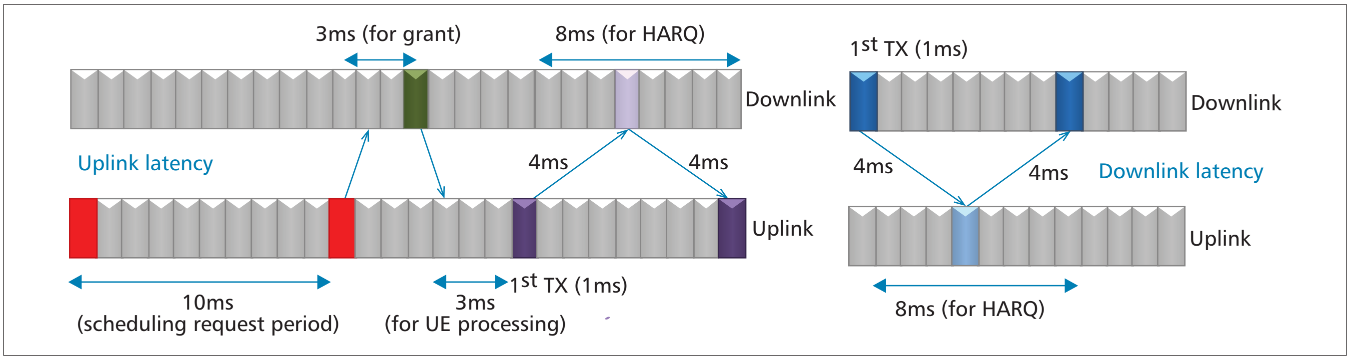

Figure 4. Uplink and downlink latency considering grant procedure and HARQ, where average HARQ delay is 0.8ms assuming a 10 percent BLER and a maximum of 1 retransmission.

TTI	SR	Grant	UE Proc	FA	TTI	Average HARQ delay	eNB Proc	Total uplink latency	
								Grant procedure	Grant-less procedure
1ms	6ms	3ms	3ms	0.5ms	1ms	0.8ms	1.5ms	15.8ms	4.8ms
0.5ms	3ms	1.5ms	1.5ms	0.25ms	0.5ms	0.4ms	0.75ms	7.9ms	2.4ms
0.07ms	0.43ms	0.21ms	0.21ms	0.04ms	0.07ms	0.06ms	0.11ms	1.13ms	0.35ms

Table 1. Latency analysis depending on TTI lengths, where UE processing time (UE Proc) is 1 TTI length for grant-less case and frame alignment (FA) time is half of TTI length.

V2X

A vehicle-centric communications network is one of the key enabling technologies for the emerging 'connected car' ecosystem, supporting a broad range of new services and applications, including automotive safety, autonomous vehicles, telematics, traffic control, and infotainment. 3GPP started studies of the use of LTE mobile networks to enable connectivity between vehicles (V2V), between vehicles and roadway infrastructure (V2I), and between vehicles and pedestrians (V2P) or other mobile users, jointly known as LTE V2X, as shown in Fig. 5.

As a wide array of different sensing and positioning technologies (e.g. mmWave radar, video, and high-precision GNSS) become standard automotive features, one key V2X service is the timely and reliable delivery of critical messages to improve safety and traffic congestion. However, the exchange of these messages can be challenging due to a large variation in message sizes, strict end-to-end latency requirements, a potential range of several hundred meters, and support of high Doppler spread when, for example, two vehicles are directly approaching each other while each one is traveling at a speed of 140km/h (equivalent Doppler speed of 280 km/h).

LTE V2X is 3GPP's response to increasing market interest as well as increasing expectations that regulatory bodies worldwide consider technology requirements and potential mandates in the next few years for vehicle communication networks. For example, Korea, Japan, the EU, and the US have allocated frequency spectrum in the 5.8-5.9 GHz range for dedicated short range communications (DSRC) to support intelligent transportation systems (ITS). In China, CCSA has also conducted studies of the feasibility of providing vehicle safety services over LTE, and it is expected that the National Regulatory Authority in China will allocate dedicated frequency spectrum for V2X. It is envisioned that LTE V2X could be deployed on licensed or shared spectrum, and it supports operation outside of the infrastructure network coverage with technologies such as enhanced D2D communications.

Alternative technologies have been developed for V2X applications and have been the subject of many academic and industry research projects and trials, with the most prominent being the IEEE WAVE and 802.11p standards. However, LTE V2X is a very attractive candidate due to its fundamental support for wide-area coverage, mobility, and spectrally efficient V2I broadcast services using eMBMS. Meanwhile, flexible and scalable resource allocation functionalities for V2V and V2P can be built upon the recently introduced proximity services (ProSe) functionalities (also known as D2D).

The feasibility study of V2X [12] is expected to evaluate the performance of different LTE-based solutions for providing V2V, V2I, and V2P services, with the goal of specifying identified enhancements starting in Rel-14. Support for V2V and V2P over D2D communication links between UEs is being studied with the highest priority, including potential resource allocation and channel estimation enhancements to support efficient and robust transmissions with low-latency. In addition, provisioning of V2X services over the link between the LTE network and the UE is also within the scope of the study, including the applicability of latency reduction and multi-cell multicast/broadcast enhancements to sufficiently meet industry and regulatory requirements for

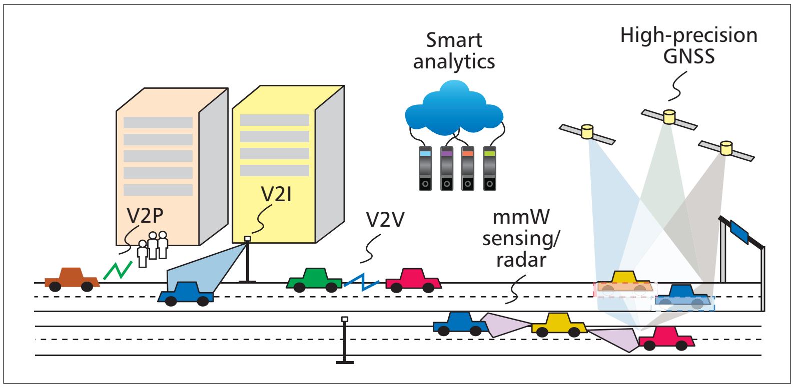

Figure 5. Overview of V2X scenarios and component technologies.

V2X. While the V2X study item is still continuing, taking into account the urgent request from industries, a work item to specify V2V support started in December 2015, with the targeted completion date of September 2016 [13].

Enhanced Downlink Multiuser Transmission Using Superposition Coding

Support of simultaneous non-orthogonal transmissions without spatial separation on the downlink has the potential to further improve system capacity. For example, downlink transmissions to a UE located at the cell boundary and to another UE located at the cell center can be scheduled using the same beam. The former UE would typically be allocated a large transmit power, and hence its interference to the latter UE can be cancelled before decoding the desired signal at the latter UE. Possible performance benefits and required specification support to assist intra-cell interference cancellation or suppression at the UE receiver were studied in Rel-13 [14] for preparation of potential specification work in Rel-14.

Conclusion

In this article we have introduced a set of features for the evolution of LTE-Advanced that are expected to be specified in 3GPP Rel-13/14, taking into account the latest status of discussions in 3GPP. These timely enhancements would allow the cellular industry to improve the efficiency of the network, and in the meantime continue to benefit from the massive economies of scale associated with the current ecosystem developed around LTE/LTE-Advanced standards from Rel-8 to Rel-12. We also expect that they would serve as the bridge from 4G to 5G, taking into account that 5G would consist of both the continued evolution of LTE-Advanced and the introduction of non-backward compatible breakthrough technologies.

References

[1] J.C. Zhang, S. Ariyavisitakul, and M. Tao, "LTE-Advanced and 4G Wireless Communications (Guest Editorial)," *IEEE Commun. Mag.*, vol. 50, no. 2, 2012, pp. 102–03.
[2] 3GPP TR 36.912, "Feasibility Study for Further Advancements for E-UTRA (LTE-Advanced)," 2010.
[3] ITU-R WP-5D, Document 5D/TEMP/625-E, "IMT Vision — Framework and Overall Objectives of the Future Development of IMT for 2020 and Beyond."
[4] 3GPP TR 36.873, "Study on 3D Channel Model for LTE," 2014
[5] 3GPP TR 36.897, "Study on Elevation Beamforming/Full-Dimension (FD) MIMO for LTE," 2015.
[6] Y. Kim *et al.*, "Full Dimension MIMO (FD-MIMO): The Next Evolution of MIMO in LTE Systems," *IEEE Wireless Commun.*, vol. 21, no. 2, 2014, pp. 26–33.
[7] 3GPP TR 36.889, "Study on Licensed-Assisted Access Using LTE," 2015.
[8] ETSI, EN 301.893, "Broadband Radio Access Networks (BRAN); 5 GHz High Performance RLAN; Harmonized EN Covering the Essential Requirements of Article 3.2 of the R&TTE Directive," 2015.
[9] 3GPP TR 36.888, "Study on Provision of Low-Cost Machine-Type Communications (MTC) User Equipments (UEs) Based on LTE," 2012.
[10] 3GPP RAN Tdoc RP-151621, "New WI Proposal: Narrow Band IOT," approved in RAN plenary #69 meeting, Sept. 2015.
[11] 3GPP RAN Tdoc RP-150465, "New SI Proposal: Study on Latency Reduction Techniques for LTE," approved in RAN plenary #67 meeting, Mar. 2015.
[12] 3GPP RAN Tdoc RP-151109, "New SI Proposal: Feasibility Study on LTE-based V2X Services," approved in RAN plenary #68 meeting, June 2015.
[13] 3GPP RAN Tdoc RP-152293, "New WI Proposal: Support for V2V Services Based on LTE Sidelink," approved in RAN plenary #70 meeting.
[14] 3GPP TR 36.859, "Study on Downlink Multiuser Superposition Transmission for LTE," 2015.

Biographies

Juho Lee (juho95.lee@samsung.com) is currently a Master with Samsung Electronics and is the lead executive in charge of research on standardization of wireless communications. He received his B.S., M.S., and Ph.D. degrees in electrical engineering from Korea Advanced Institute of Science and Technology (KAIST), Korea, in 1993, 1995, and 2000, respectively. He joined Samsung Electronics in 2000 and has been working on standardization of mobile communications for 3G and 4G such as WCDMA, HSDPA, HUSPA, LTE, and LTE-Advanced. He is also actively working on research and standardization for 5G. He was a vice chairman of 3GPP TSG RAN WG1 from February 2003 to August 2009, chaired LTE/LTE-Advanced MIMO sessions, and served as the rapporteur for the 3GPP LTE-Advanced Rel-11 CoMP work item.

Younsun Kim (younsun@samsung.com) received his B.S. and M.S. degrees in electronic engineering from Yonsei University, Korea, and his Ph.D. degree in electrical engineering from the University of Washington in 1996, 1999, and 2009, respectively. He joined Samsung Electronics in 1999, and has since been working on the standardization of wireless communication systems such as cdma2000, HRPD, and recently LTE/LTE-A. His research interests include multiple access schemes, network coordination schemes, advanced receiver algorithms, and advanced antenna techniques for next generation systems.

Yongjun Kwak (yongjun.kwak@samsung.com) received his B.S. degree in electronics and electrical engineering from POSTECH, Korea, his M.S. degree in electrical engineering from KAIST, Korea, and the Ph.D. degree in engineering sciences from Harvard University, USA in 1998, 2000, and 2012, respectively. He joined Samsung Electronics in 2000 and has been working on physical layer standardization of WCDMA, HSDPA, HUSPA, and LTE technologies. His research interests include multiple access, channel coding, system design for 5G wireless communication systems.

Jianzhong (Charlie) Zhang (Jianzhong.z@samsung.com) is currently a vice president and head of the Standards and Research Lab with Samsung Research America in Dallas, where he leads research and standards for 5G cellular systems as well as next generation multimedia networks. From August 2009 to August 2013 he served as the vice chairman of the 3GPP RAN1 working group and led development of LTE and LTE-Advanced technologies such as 3D channel modeling, UL-MIMO and CoMP, carrier aggregation for TD-LTE, etc. Before joining Samsung he was with Motorola from 2006 to 2007 working on 3GPP HSPA standards, and with Nokia Research Center from 2001 to 2006 working on the IEEE 802.16e (WiMAX) standard and EDGE/CDMA receiver algorithms. He received his Ph.D. degree from the University of Wisconsin, Madison.

Aris Papasakellariou (aris.papas@samsung.com) received his B.S. degree in physics from the University of Athens, Greece, and his M.S. and Ph.D. degrees from Rice University in 1991, 1993, and 1996, respectively. He joined Samsung Electronics in 2007 and has been working on 3GPP standardization since 2005.

Thomas Novlan (t.novlan@samsung.com) received his B.S. with high honors, M.S., and Ph.D., in electrical engineering from the University of Texas at Austin in 2007, 2009, and 2012, respectively. He joined Samsung Electronics in 2012 and is working on wireless communications research and LTE-A standardization for device-to-device and small cell-related technologies.

Chengjun Sun (chengjun.sun@samsung.com) received his B.S., M.S., and Ph.D. degrees in signal and information processing from Harbin Institute of Technology (HIT), China, in 1997, 1999 and 2002, respectively. He joined Samsung Electronics in 2003 and has been working on standardization of mobile communications such as TD-SCDMA, WCDMA, HSUPA, LTE, and LTE-Advanced. His research interests include link adaptation, duplexing, radio resource management, and carrier aggregation for next generation systems.

Yingyang Li (yingyang2.li@samsung.com) received his B.S. degree on communications from Nanjing University of Posts & Telecommunications (NUPT) in 2001, and his M.S. degree oi mobie communication from Beijing University of Posts & Telecommunications (BUPT) in 2004. He joined Samsung Electronics in 2004 and has been working on the standardization of mobile communications such as WCDMA, LTE, and LTE-Advanced. His research interests include multiple access schemes, duplexing, and carrier aggregation for next generation systems.