LTE-Advanced: The Path towards Gigabit/s in Wireless Mobile Communication

Term Paper

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Herewith I declare that I have made this term paper myself and all the sources I used is cited as References.

Oleg Getmanchuk
1. Introduction – LTE and LTE-Advanced

LTE-Advanced (LTE-A) is the project name of the evolved version of LTE that is being developed by 3GPP (3rd Generation Partnership Project). LTE-A meet or exceed the requirements of the International Telecommunication Union (ITU) for the fourth generation (4G) radio communication standard known as IMT-Advanced. The ITU has coined the term IMT-Advanced to identify mobile systems whose capabilities go beyond those of IMT 2000 (has been widely referred to as 3G). Specifically data rate requirements have been increased in order to support advanced services and applications. 1Gbps for low mobility scenarios must be realized. In September 2009 the 3GPP Partners made a formal submission to the ITU proposing that LTE Release 10 & beyond (LTE-Advanced) should be evaluated as a candidate for IMT-Advanced. And in January 2012 the ITU finally decided that LTE-Advanced and WirelessMAN-Advanced (commonly known as WiMAX 2) both qualify and are officially designated as IMT-Advanced technologies.

Throughout the World, we continue to witness exponential growth in mobile broadband traffic, thereby fourth generation wireless technology has been anticipated for quite some time. To understand the evolutionary changes in 4G and LTE-Advanced, it may be helpful to summarize what came before.

Wireless communications have evolved from the so-called second generation (2G) systems of the early 1990s, which first introduced digital cellular technology, through the deployment of third generation (3G) systems with their higher speed data networks to the fourth generation technology being developed today. This evolution is illustrated in Figure 1, which shows that fewer standards are being proposed for 4G than in previous generations, with only two that are accorded the official designation of IMT-Advanced today: 3GPP LTE-Advanced and WirelessMAN-Advanced (IEEE 802.16m).

Early 3G systems, of which there were five, did not immediately meet the ITU 2 Mbps peak data rate targets in practical deployment although they did in theory. However, there have been improvements to the standards since then that have brought deployed systems closer to and now well beyond the original 3G targets.

The introduction of LTE was driven by the industry’s quest for a more efficient technology that could help deliver ever faster mobile broadband services. In comparison with basic HSPA networks, LTE delivered this enhancement by offering the state of the art combination of new air interface base technology (OFDMA/SC-FDMA), greater flexibility for utilizing spectrum like for example support of 20MHz bands and TD-LTE for using unpaired spectrum, as well as a toolbox to support further enhancements like MIMO and Higher Order Modulation. This allows LTE to be flexibly deployed where other systems exist today, including narrowband systems such as GSM and some systems in the U.S. based on 1.25 MHz. LTE Release 8 specifications support peak data rates exceeding 300Mbit/s in DL and more than 75 Mbit/s in UL. LTE also supports very low user plane latency of 10ms and control plane (idle to active mode) latency of less than 100ms. In terms of mobility, LTE is aimed primarily at low mobility applications in the 0 to 15 km/h range, where the highest performance will be seen. The system is capable of working at higher speeds and will be supported with high performance from 15 to 120 km/h and functional support from 120 to 350 km/h.

LTE has been a commercial success, going by its adoption rate, which has exceeded any other mobile network technology. By the beginning of 2012 year 285 operators have committed to commercial LTE network deployments or are engaged in trials, technology testing or studies.3

2. 3GPP targets for LTE-Advanced

One of the main drivers of the technical enhancements and timetable for LTE-A development has been ITU-R Circular Letter requesting candidate submissions for IMT-Advanced radio interface technologies, 3GPP determined that LTE-Advanced would meet the ITU requirements for 4G.

The ITU’s high level requirements for IMT-Advanced include the following:

- A high degree of common functionality worldwide while retaining the flexibility to support a wide range of local services and applications in a cost-efficient manner
- Compatibility of services within IMT and with fixed networks
- Capability for interworking with other radio systems
- High quality mobile services
- User equipment suitable for worldwide use
- User-friendly applications, services, and equipment
- Worldwide roaming capability
- Enhanced peak data rates to support advanced mobile services and applications (in the downlink, 100 Mbps for high mobility and 1 Gbps for low mobility)

Further, it was determined that 3GPP Release 8 LTE could meet most of the 4G requirements apart from uplink spectral efficiency and the peak data rates. These higher requirements are addressed with the addition of the following LTE-Advanced features:

- Wider bandwidths, enabled by carrier aggregation
- Higher efficiency, enabled by enhanced uplink multiple access and enhanced multiple antenna transmission (advanced MIMO techniques)

Other performance enhancements Release 10, even though they are not critical to meeting 4G requirements:

- Backward compatibility of LTE-Advanced with LTE. An LTE terminal should be able to work in an LTE-Advanced network and vice versa.
- Coordinated multipoint transmission and reception (CoMP)
- Relaying
- Support for heterogeneous networks
- LTE self-optimizing network (SON) enhancements

In addition, spectral efficiency targets have been defined for different transmit and receive antenna configurations in a 10 MHz system bandwidth. The LTE-Advanced targets are approximately 50% higher than the corresponding performance figures for LTE Release 8. Table 1 compares the spectral efficiency targets for LTE, LTE-Advanced, and IMT-Advanced.

### Table 1 Performance targets for LTE, Advanced-LTE, and IMT-Advanced

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<tbody>
<tr>
<td>Peak spectral efficiency (b/s/Hz)</td>
<td>Downlink</td>
<td>16.3 (4x4 MIMO)</td>
<td>30 (up to 8x8 MIMO)</td>
<td>15 (4x4 MIMO)</td>
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<tr>
<td></td>
<td>Uplink</td>
<td>4.32 (64 QAM SISO)</td>
<td>15 (up to 4x4 MIMO)</td>
<td>6.75 (2x4 MIMO)</td>
</tr>
<tr>
<td>Downlink cell spectral efficiency (b/s/Hz), 3 km/h, 500 m ISD</td>
<td>2x2 MIMO</td>
<td>1.69</td>
<td>2.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.2 MIMO</td>
<td>1.87</td>
<td>2.6</td>
<td>2.6</td>
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<tr>
<td></td>
<td>4x4 MIMO</td>
<td>2.67</td>
<td>3.7</td>
<td></td>
</tr>
<tr>
<td>Downlink cell-edge user spectral efficiency (b/s/Hz), 5 percentile, 10 users, 500 m ISD</td>
<td>2x2 MIMO</td>
<td>0.05</td>
<td>0.07</td>
<td></td>
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<tr>
<td></td>
<td>4x2 MIMO</td>
<td>0.06</td>
<td>0.09</td>
<td>0.075</td>
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<tr>
<td></td>
<td>4x4 MIMO</td>
<td>0.08</td>
<td>0.12</td>
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*Note: ISD = Inter-site distance*

LTE-Advanced shall operate in spectrum allocations of different sizes including wider spectrum allocations than those of LTE Release 8. Although it is desirable to have bandwidths greater than 20 MHz deployed in adjacent spectrum, the limited availability of spectrum means that aggregation from different bands is necessary to meet the higher bandwidth requirements. This option has been allowed for in the IMT-Advanced specifications.

3. LTE-Advanced technology components

3.1. Bandwidth extension

Achieving the 4G target downlink peak data rate of 1 Gbps will require wider channel bandwidths than are currently specified in LTE Release 8. At the moment, LTE supports channel bandwidths up to 20 MHz, and it is unlikely that spectral efficiency can be improved much beyond current LTE performance targets. One straightforward possibility to reach high data rates requirements is to aggregate multiple LTE carrier (see Figure 2). Two or more component carrier are aggregated in order to support wider transmission bandwidths up to 100MHz.

![Figure 2 LTE-Advanced maximum bandwidth in contiguous deployment](http://www2.rohde-schwarz.com/file_13924/1MA169_2E.pdf)

Because most spectrum is occupied and 100 MHz of contiguous spectrum is not available to most operators, the ITU has allowed the creation of wider bandwidths through the aggregation of contiguous and non-contiguous component carriers (see Figure 3). It enables operators to provide high throughput without wide contiguous frequency band allocations, and ensures statistical multiplexing gain by distributing the traffic dynamically over multiple carriers. In order to support legacy LTE Release 8 terminals it is required that each of the component carriers must be compatible with LTE Release 8.

![Figure 3 LTE-Advanced non-contiguous spectrum deployment](http://www2.rohde-schwarz.com/file_13924/1MA169_2E.pdf)

Up to 5 component carriers may be aggregated. An LTE-Advanced user equipment (UE) cannot be configured with more uplink component carriers than downlink component carriers, and in typical time division duplex (TDD) deployments the number of uplink and downlink component carriers, as well as the bandwidth of each, must be the same.

With Carrier Aggregation, operators can take asymmetrical bands into use with FDD since there can be uplink or downlink only frequency bands. Aggregated carriers can be adjacent or non-adjacent even at different frequency bands, so basically all the frequency allocations can be used. There are a lot of permutations and combinations, and some of them are a bit more difficult to implement due to

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5 [http://www2.rohde-schwarz.com/file_13924/1MA169_2E.pdf](http://www2.rohde-schwarz.com/file_13924/1MA169_2E.pdf)
6 [http://www2.rohde-schwarz.com/file_13924/1MA169_2E.pdf](http://www2.rohde-schwarz.com/file_13924/1MA169_2E.pdf)
interference problems caused e.g. by intermodulation products of transmitted signals on different frequency bands. Therefore, only intraband carrier aggregation is supported in uplink in LTE Release 10, while a higher range of band combinations will be supported in later releases.

3.2. Improved MIMO schemes

Multi-antenna or MIMO (Multiple Input, Multiple Output) technology is based on transmitting and receiving with multiple antennas and utilizing uncorrelated communication channels when radio signals propagate through the physical environment. If there is enough isolation between the communication channels, then multiple data transmissions can share the same frequency resources. If the multiple transmissions are for a single user, then the technology is called Single-User MIMO (SU-MIMO), for multiple users Multi-User MIMO (MU-MIMO). The better the system can utilize these communication channels for multiple transmissions, the higher is the capacity that the system can provide.

LTE Release 8 supports MIMO schemes in both downlink and uplink direction. In downlink direction up to four transmit antennas may be used. In uplink direction only single antenna transmission is used. Considering the defined UE capability classes one can expect two antenna operation in downlink and one antenna operation in uplink to be the standard case for initial LTE deployment. LTE-Advanced extends the MIMO support to eight downlink antennas and four uplink antennas (see Figure 4).

![Figure 4 Supported transmit layers in LTE Release 8 and LTE-Advanced](http://www2.rohde-schwarz.com/file_13924/1MA169_2E.pdf)

Release 10 has enhanced the reference signal design with user specific reference symbols for signal demodulation and common reference symbols for feedback purposes in downlink and more orthogonal reference signal structure in uplink. The enhanced design enables better performance when the number of antenna branches is high.

Downlink MIMO has already been included in LTE Release 8. The LTE Release 8 codebook and reference symbol design was found to be quite optimum for two and four transmit antennas (2x2, 2x4 and 4x4 antenna configurations), but the channel state information feedback from UE to eNB could have been more accurate. This limitation is overcome by the new reference symbol design of Release 10, which is also more effective when the number of transmit antennas is higher. Based on the studies and numerous contributions in 3GPP, it can be safely concluded that the higher the number of antennas, the higher is the gain that Release 10 MIMO provides in downlink.
Uplink MIMO provides significantly higher peak rates and improved spectrum efficiency in uplink direction. SU-MIMO provides mainly increased data rates in lightly loaded networks for high-end multi-transmitter UE, whereas MU-MIMO can offer significant improvement of spectrum efficiency even with single transmitter UE. The LTE-A system can operate in both SU and MU-MIMO modes at the same time using dynamic user specific MIMO transmission configuration.

LTE uplink is based on SC-FDMA, a powerful technology that combines many of the flexible aspects of OFDM with the low peak to average power ratio (PAPR) of a single carrier system. However, SC-FDMA requires carrier allocation across a contiguous block of spectrum and this prevents some of the scheduling flexibility inherent in pure OFDM. LTE-Advanced enhances the uplink multiple access scheme by adopting clustered SC-FDMA, also known as discrete Fourier transform spread OFDM (DFT-S-OFDM). This scheme is similar to SC-FDMA but has the advantage that it allows non-contiguous (clustered) groups of subcarriers to be allocated for transmission by a single UE, thus enabling uplink frequency-selective scheduling and better link performance. Clustered SC-FDMA was chosen in preference to pure OFDM to avoid a significant increase in PAPR. It will help satisfy the requirement for increased uplink spectral efficiency while maintaining backward-compatibility with LTE.

3.3. Coordinated Transmission and Reception schemes

Coordinated multipoint (CoMP) is an advanced variant of MIMO considered for LTE-Advanced as a tool to improve the performance for high data rates, cell-edge throughput, and system throughput in high load and low load scenarios.

In a cellular deployment and specifically if frequencies are reused in each cell, other-cell interference traditionally degrades the system capacity. The target in CoMP is to turn the other cell interference into a useful signal specifically at the cell border. This requires dynamic coordination in the scheduling/transmission, including joint transmission, from multiple geographically separate points and also support for joint processing of received signals at multiple geographically separated points as illustrated in Figure 5.

![Figure 5 Example of CoMP in a distributed network architecture](http://www2.rohde-schwarz.com/file_13924/1MA169_2E.pdf)

Coordinated multipoint transmission and reception (CoMP) shows great potential to improve the cell edge performance and system capacity. However, the technology was not seen mature enough for including it in Release 10. It has been demonstrated with simulations and field tests that CoMP technologies have high potential from a single user point of view but there are open issues on the operation of large scale
networks and the signalling between UE and network to characterize the radio environment for multi-site transmission. Signalling should provide enough information to enable high performance, but not at the cost of excessive overhead or additional energy and radio resource consumption.\(^9\)

### 3.4. Relay Nodes

![Figure 6 Relay Node deployment\(^10\).](image)

Relay nodes enable the deployment of small cells at locations where conventional fixed line or microwave backhaul is not possible or commercially viable. LTE Release 8 supports simple amplify and forward relays (also called repeaters) that can be used for coverage extension. However, those do not use the radio resources efficiently. Typically they receive and retransmit an entire frequency band, so they must be sited carefully. In general, repeaters can improve coverage but do not substantially increase capacity. More advanced relays at layer 2 can decode transmissions before retransmitting them. Traffic can then be forwarded selectively to and from the UE local to the RN, thus minimizing the interference created by legacy relays that forward all traffic. The enhanced relaying technology in LTE-A is based on selfbackhauling base stations sharing features with (pico) base stations. LTE Release 10 specifies a new interface Un between Donor eNB and Relay Node (RN). The new interface uses MBSFN (Multicast-Broadcast Single Frequency Network) subframes which were introduced in Release 8 already to hide the Un interface from UE operating on the same carrier and thus make it fully backward compatible: UE interprets Un transmission as MBSFN transmission for which they are not subscribed and simply ignore them. The so called Proxy S1/X2 concept forwards both S1 and X2 messages towards the RN transparently for the Core Network which sees a Relay Node as a sector of the Donor eNB as well. Thus relaying is also backwards compatible for both the MME and Serving Gateway which serve the UE.

### 3.5. Local area optimization features

Support for heterogeneous networks: The term “Heterogeneous Networks” does not necessarily refer to a specific technology or feature as such, but is instead used to describe networks that have both wide area

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and local area (small cell) deployments. Release 10 intends to address the support needs of heterogeneous networks that combine low power nodes (such as picocells, femtocells, repeaters, and RNs) within a macrocell. As the network becomes more complex, the subject of radio resource management is growing in importance. Work is ongoing to develop more advanced methods of radio resource management including new self-optimizing network (SON) features. The Release 10 specifications also continue to develop the use of femtocells and home base stations (HeNBs) introduced in Release 9 as a means of improving network efficiencies and reducing infrastructure costs.

LTE self-optimizing networks: Cost of deployment and operation can be decreased with self-organizing and optimization technologies. The main aspects of SON can be summarized as follows:

- **Self-configuration**—The one-time process of automating a specific event, such as the introduction of a new femtocell, by making use of the O&M interface and the network management module
- **Self-optimization**—The continuous process of using environmental data, such as UE and base station measurements, to optimize the current network settings within the constraints set by the configuration process
- **Self-healing**—The process of recovering from an exceptional event caused by unusual circumstances, such as dramatically changing interference conditions or the detection of a ping pong situation in which a UE continuously switches between macro and femtocells.

### 4. Outlook

There is no doubt about ability LTE-Advanced to rich 1 Gigabit/s in Wireless Mobile Communications, in fact there was two demonstrations, one has done by Ericsson\(^{11}\) and the second by Nokia Siemens Networks\(^{12}\).

The telecom equipment provider Ericsson was given test spectrum by the Swedish Post and Telecom Agency, and the demonstration was done driving around in a van. The captions under the test van pictures say 900+ Mbps. The demo system was based on Ericsson’s multi-mode, multi-standard radio base station, RBS 6000. Live traffic was streamed between the RBS and a moving van from which network performance could be monitored. In the demonstration, 60MHz of aggregated bandwidth and 8x8 MIMO was used.

Nokia Siemens Networks achieved world record data speeds exceeding 1.4 Gbps using an LTE-Advanced system on 100 MHz of aggregated spectrum. The calls, involving huge file transfers and HD video streaming, hit peaks of 1.429 Gigabits-per-second. To made this Nokia Siemens Networks used commercial Flexi Multiradio 10 Base Station.

LTE-Advanced will ultimately have a huge impact on the mobile networks and the devices that use them, but users should not expect 1 Gbps speeds to suddenly pop on their phones next year. While the standards call for networks that will eventually support 1 Gbps speeds to stationary devices, that’s more of theoretical aspiration than a realistic goal. At first, to deliver 1 Gbps speeds an operator would need 40 MHz of spectrum and 8×8 MIMO antenna solution, or about 100 MHz of spectrum without using MIMO, which is a lot of spectrum and eight antennas that would have to be crammed on both the base station and inside the device. For example in the United States, carriers don’t have the kind of spectral assets that are

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required to get all the benefits of LTE-Advanced. Verizon’s 4G LTE network, one of the biggest 4G LTE network in the world, uses two 10 MHz channels in several markets. They’d like to use more spectrum, and they’re currently trying to buy some more, but they’re rightfully getting some push back from T-Mobile who wants the market to remain competitive. Another thing, MIMO antennas can’t be stacked on top of one another like stogies in a cigar box; they need their space to work. So, unless you want to carry a device the size of a Volkswagen in your pocket, you won’t be getting an eight-antenna device — and their fast speeds — any time soon. At the same time each antenna draws the power equivalent of single cellphone connection. Battery efficiency will have to improve immensely before handset makers can think about eight, or even four, MIMO antennas to any mobile device.

LTE-Advanced won’t come out as a single new network like LTE did, but rather, in waves. It’s more like a menu of technologies: Operators will select whatever technology or technique that looks tastiest at the time, implement it in their current LTE networks, and when they get hungry for more speed, capacity or efficiency, they will return to their vendors for another meal.

The upgrade to LTE Advanced, which most carriers will do gradually, is similar to adding lanes to a highway, said analyst Monica Paolini of Senza Fili Consulting. Drivers don’t necessarily go faster on a multilane highway, but the additional lanes are needed if more drivers want to go full speed in the future. LTE Advanced adds those "lanes" for wireless connections. "Capacity might not be an issue today, but it is going to become an issue pretty soon," she said.13

Cars or Trains may being the ideal candidates to gain the full benefits of MIMO and LTE-Advanced. Unlike our phones, cars have alternators, which can supply the power demands eight antennas would require. Additionally, fixed mobile convergence in LTE-Advanced will allow for DSL internet connections in rural areas that use LTE as the backend instead of the landline networks. Going forward, we can expect low-cost DSL to be implemented in rural areas with LTE-Advanced technology because it is much cheaper to deploy. This will hopefully bring down the cost of fixed broadband even more.

Several operators have already claimed about launching LTE-Advanced in 2013.14 But 3 or 4 years will pass before operators will start deploying it widely in end-user devices according to telecommunications equipment makers. There will also be continual upgrades to the standard which adds new features.

5. Conclusion

Unlike the original Long Term Evolution networks, which brought a boost in mobile broadband speeds, LTE-Advanced won’t be so much about speed, it’s about saving money. LTE-A provides a powerful and versatile toolbox, which helps network operators to differentiate in mobile broadband user experience and to increase network efficiency.

The LTE-Advanced standard is made up of several components, of which service providers can use some or all, said analyst Peter Jarich of Current Analysis. These include aggregation of separate spectrum bands, better integration between small and large cells, the use of four or more antennas in a device, and relay devices at the edges of cells. Heterogeneous networking is another promising tool in the new standard,

13 http://www.pcworld.com/businesscenter/article/248772/lteadvanced_is_the_future_but_no_rocket_ship.html
14 http://www.fiercebroadbandwireless.com/special-reports/us-lte-buildout-timelines
Jarich said. It includes mechanisms to make conventional macro cells work better with the smaller cells now being developed to better serve crowded and indoor areas.¹⁵

"The best way to describe LTE Advanced is to say it’s a long roadmap of capabilities after you launch the first set," said Iyad Tarazi, vice president of network development and engineering for Sprint Nextel.¹⁶

¹⁵ http://www.pcworld.com/businesscenter/article/248772/lteadvanced_is_the_future_but_no_rocket_ship.html
## Acronyms

<table>
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<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>2G</td>
<td>Second Generation</td>
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<td>3G</td>
<td>Third Generation</td>
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<td>3GPP</td>
<td>Third Generation Partnership Project</td>
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<td>4G</td>
<td>Fourth Generation</td>
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<td>CDMA</td>
<td>Code Division Multiple Access</td>
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<td>CoMP</td>
<td>Cooperative Multipoint</td>
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<td>DFT-S-OFDM</td>
<td>Discrete Fourier Transform Spread Orthogonal Frequency Division Multiplexing</td>
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<td>E-DCH</td>
<td>Enhanced Dedicated Channel</td>
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<td>eNB</td>
<td>Evolved Node B</td>
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<td>FDD</td>
<td>Frequency Division Duplex</td>
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<td>GSM</td>
<td>Global System for Mobile Communication</td>
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<tr>
<td>HeNB</td>
<td>Home eNB</td>
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<td>HSDPA</td>
<td>High Speed Downlink Packet Access</td>
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<td>MIMO</td>
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<td>Relay Node</td>
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<tr>
<td>SC-FDMA</td>
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<td>Time Division Duplex</td>
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<td>User Equipment</td>
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<tr>
<td>UMTS</td>
<td>Universal Mobile Telecommunications System</td>
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