An Analysis of LTE and Small Cells

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1. Introduction to LTE

1.1 Overview

LTE, or Long Term Evolution, is a new standard for wireless communication developed by the 3rd Generation Partnership Project (3GPP) with a major design goal of providing up to ten times the speed of 3G networks for use with mobile devices such as smartphones, netbooks, and tablets. LTE is one of the two candidates for 4G-the fourth generation of mobile phone communication standards. Being a 4G system and a successor to 3G technologies, LTE will naturally have a different system architecture and protocol functionality, which will both be analyzed in this paper. The LTE wireless communication standard will offer many improvements over 3G schemes, with some expected drawbacks.

First and foremost, LTE will offer download rates of approximately 300Mbps and upload rates of approximately 75Mbps. LTE actually has a simpler core architecture than previous wireless standards, and does not require a reconstruction of the entire network from the ground up. This allows current wireless broadband providers to upgrade and transition to this new technology. Despite this, there will still need to be a large amount of expensive new equipment purchased, which leads to exorbitant start-up costs for service providers.

LTE also offers another difficulty for service-providers in the form of data traffic rebalancing. Traditionally, network resources have been balanced to carry voice and messaging with a small amount of data. Effective load-balancing will need to take place by the service providers.

One positive aspect of the simplification of the LTE core architecture is the decentralization of control logic, although LTE will still effectively have a main control-node through the use of Mobility Management Entities.

The LTE standard also supports only packet switching in its all-IP network. Voice calls in GSM, UMTS, and CDMA2000 are all circuit-switched, so carriers must adapt this to LTE. Three different approaches are VoLTE (Voice Over LTE), CSFB (Circuit-Switched Fallback), and SVLTE (Simultaneous Voice and LTE).

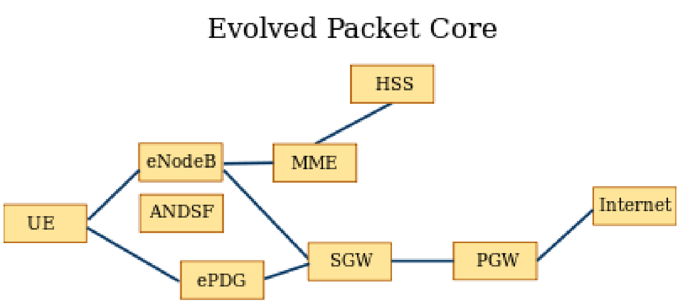
SVLTE is the approach where handsets will work simultaneously in LTE and circuit-switched modes of operation, with LTE for data services and circuit-switched mode for voice services. Using CSFB, LTE will be used for data, and when a voice call is to be initiated or received, there will be a fallback to the circuit switched domain. VoLTE will result in voice being delivered as data flows within the LTE data bearer, and as such will not require any of the legacy circuit-switched voice network to be maintained. LTE cell sizes can range from tens of meters (small cells) up to approximately 100km radius macrocells. Lower frequency bands can be used over a larger range for varying levels of performance depending upon population and desired service. Higher frequency bands will be used to support high-speed mobile broadband to urban areas, with cell sizes of under 1km.

1.2 A Brief Timeline of LTE

Long Term Evolution was first proposed by NTT DoCoMo of Japan in **2004**. Studies for the new standard began as early as **2005**. In **May of 2007**, the LTSI (LTE/SAE Trial Initiative) Alliance was formed for the purpose of global collaboration between vendors and operators in an effort of verification and LTE promotion such that the technology could be implemented as efficiently and as quickly as possible. Ericsson demonstrated LTE bit rates of up to 144 Mbps for the first time in the world in early **2007**. LTE was officially finalized in **December 2008**, with the first publicly available service in Oslo and Stockholm on **December 14,**

2009. NTT DoCoMo were able to improve upon these achieved LTE bitrates, with LTE downlink speeds of up to 200Mbps just seven months later.
In **February of 2010**, AT&T announced the rollout of LTE service in 2011.
In **August of 2010**, Alcatel-Lucent and Texas Energy Network, LLC, were able to successfully test an LTE base station over a working range of 12 kilometers. In **September of 2010**, Verizon followed suit with the announcement of their plans to have their entire 3G footprint switched to 4G by the end of 2013, with an effort to have 4G in 30 major cities by the end of 2010. In **July of 2011**, Sprint Nextel and LightSquared announce a fifteen-year deal for Sprint to use LightSquared's LTE network in return for LightSquared's utilization of Sprint Nextel's 3G network in **2012**. Verizon Wireless launched its 4G LTE network in 38 different markets on **December 6, 2010**. The area covered 100 million people in the United States (roughly one-third of the nation's population), with downlink speeds of 5 to 12 Mbps, and uplink speeds of 2-5Mbps. In **March 2011**, Release 10 specifying LTE Advanced was frozen.
Sprint Nextel officially announced plans for LTE on **September 27, 2011.**
To date, the LTE specification provides peak rates of 300Mbps for downlink and 75Mbps for uplink, with QoS provisions permitting a transfer latency of under 5ms in the RAN.

1.3 LTE Architectural Entities



In order to understand a broad concept such as LTE, it is important to comprehend the functionality of the core components of which it is composed. Below are some of the key components which make up the EPC (Evolved Packet Core) and e-UTRAN (Evolved Universal Terrestrial Radio Access Network):

UE

The UE is the User Equipment. This can range from smartphones to tablets.
In order to get service from the network, a UE must select the network and camp on a specific cell. Once this occurs, the UE will synchronize itself with the network on the frame and slot level.
The UE will require much information, such as the Network PLMN ID, the Tracking Area ID, the Cell ID, and also the Radio and Core Network capabilities for the network selection.
This information will be broadcast by the network in order to help the UE during the selection process.

E-UTRAN

E-UTRAN is the initialism described by 3GPP to be the combination of the E-UTRA LTE air interface, the UEs (User Equipment), as well as eNodeBs, which provide the user plane and control plane protocol terminations towards the UE.
The eNodeBs are interconnected with each other by means of the X2 interface, and to the Evolved Packet Core via the S1 interface (S1 MME to the Mobility Management Entity and S-U to the Serving Gateway). The S1 interface allows support for a many-to-many relationship between MMEs or SGWs and the eNodeBs.
The eNodeBs are different from Node Bs in terms of control functionality; the eNodeBs embed their own control functionality and do not require an RNC (Radio Network Controller), which helps greatly simplify the architecture, along with decreasing its response latency. The eNodeBs are also used for IP header compression, encryption of user data streams, MME selection, routing of user plane data to the SGW, radio resource management, as well as the scheduling and transmission of paging messages.

MME (Mobility Management Entity)

The MME is the main control element of the LTE access-network. Despite its name, the MME has many other key responsibilities than just mobility

management.
The MME is selected based upon its geographical distance from the served UE and according to its load. After the MME is selected, the MME will select other service elements such as the SGW or the PGW. Mobility Management Entities will repeatedly store new location reports of idle UEs, and use the most recent one for paging a UE in the last-reported tracking area.
MMEs also play a major role in the authentication process and interface directly with the HSS for getting and providing subscriber data.
The MMEs are also responsible for NAS (Non-Access Stratum) signaling and security, tracking area list management, PDN Gateway and Serving Gateway selection, inter-LTE and intra-LTE handovers, as well as bearer management.

SGW (Serving Gateway)
The Serving Gateway is responsible for routing and forwarding user data packets. It is also responsible for acting as a mobility anchor for the user plane during inter-eNodeB handovers as well as the anchor for the mobility between LTE and other 3GPP technologies.

PGW (PDN Gateway)
The Packet Data Network Gateway is responsible for providing connectivity from the UE end-user to external packet data networks. In effect, it is the point of exit and entry of traffic for the UE. A UE may be simultaneously connected to multiple PGWs for accessing more than one packet data network. The PDN Gateway is also responsible for policy enforcement, packet filtering per user, and lawful interception, among other things. The PGW is also an anchor for mobility between 3GPP technologies and non-3GPP technologies.

HSS (Home Subscriber Server)
The HSS is a central database which contains information regarding users. The HSS is responsible for mobility management, call and session establishment support, user authentication and access authorization.

ANDSF (Access Network Discovery and Selection Function)
The purpose of the ANDSF is to assist the UE to discover non-3GPP access networks like Wi-Fi or WIMAX, which can be used for data communications in addition to 3GPP access networks, and to provide the UE with rules policing the connection with these networks.
The ANDSF will also prioritize and manage these connections to non-3GPP access networks.
The Access Network Discovery and Selection Function was developed as a response to the ever-growing abundance of 3GPP-compliant UEs which were able to also access non-3GPP data networks.

ePDG (Evolved Packet Data Gateway)
The ePDG's main function is to secure the data transmission with a UE connected to the EPC over an untrusted non-3GPP access.

1.4 LTE Functionality

The Long Term Evolution standard would be nothing if not for the use of the protocols by which the architectural entities operate. These protocols handle control logic (dealing with information signals according to different design rules or constraints), passing of data between nodes, error handling, error coding with redundant information, user authentication and authorization to remote resources, among many other things. Below, some communication schemes and procedures are described briefly:

Paging
Paging is a procedure used by the network in order to request the establishment of a NAS signaling connection to the UE. If an IP packet that comes from the external network to the PDN Gateway and there is currently no dedicated bearer existing for the UE, it must forward the IP packet to the Serving Gateway on the default bearer. Once the packet has reached the Serving Gateway through the default bearer, the SGW will detect the need to create a dedicated bearer. It then sends the "Downlink Data Notification" message to the Mobility Management Entity in order to page the UE and create the dedicated bearers. The MME must ensure that the UE has established an RRC connection. For this

reason, the MME will send a Paging Request message to all eNodeBs associated with the last known Tracking Area.

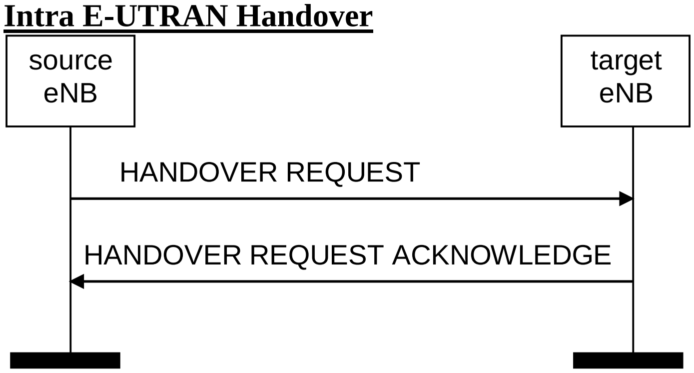
S1 Application Protocol (S1AP)

S1-MME is used for interfacing eNodeBs with Mobility Management Entities, while S1-U is used for interfacing eNodeBs with Serving Gateways for user plane traffic. Collectively, the S1-U and S1-MME interfaces are known as the S1 interface, which is effectively the interface from the eNodeB (components of e-UTRANs) and the Evolved Packet Core.

X2 Application Protocol (X2AP)

The X2 Application Protocol is used for the coordination fo handovers and for performing load management between various eNodeB network elements. It is used to allow for the mobility of UEs within the LTE radio access network by providing the following functions: mobility management, load-balancing, reporting of error situations, resetting and setting up the X2, as well as eNodeB configuration updates.

Intra E-UTRAN Handover



The source eNodeB will initiate the handover by sending a HANDOVER REQUEST message to the target eNodeB. When the source eNodeB sends this message, it will also start a timer $TRELOC_{prep}$.
If allowed, the target eNodeB will reserve resources, send the HANDOVER REQUEST ACKNOWLEDGE message back to the source eNodeB. When the source eNodeB receives the HANDOVER REQUEST ACKNOWLEDGE message, it will stop the timer $TRELOC_{prep}$, start another timer ($TX2RELOC_{overall}$) and terminate the Handover Preparation procedure. During handover, the User Plane (UP) will ensure lossless mobility while the Control Plane (CP) will provide eNodeB relocation capability.
In simplification, a UE is in connection with a cell, but a situation occurs that requires and handover to happen. The network will send "signal quality measurement" command (RRC Connection Reconfiguration) to the UE for the target cell to which it will hand over to. The UE performance measurement report will be sent to the network via the current cell and the network will evaluate this measurement result reported by the UE. If the evaluation results turn out to require a handover, the network will send the Change Cell command (RRC Connection Reconfiguration) to the UE. The UE will then perform the cell change process, and, once complete, send a message to the network of "cell change completion" (RRC Connection Reconfiguration Complete) through the new cell.

3. Small Cell Overview

Small cells are low-powered radio access nodes with a range from 10 meters to approximately 2km, which is considerably smaller than the mobile macrocells, which are typically in the range of a few tens of kilometers. Small cells are important for data offloading, and are seen as a vital tool for managing the LTE Advanced spectrum much more efficiently than can be done by just utilizing macrocells.
Small cells are used to provide both indoor and outdoor wireless service. Small cells are also used by mobile operators in an effort to extend their service coverage or to increase the network capacity. With the use of small cells, it is estimated that mobile operators can offload traffic by as high as 80% during peak usage times.
There are three main types of small cells: femtocells, picocells, and microcells, of which femtocells are the most common form.
Picocells and microcells are different from femtocells in that they do not always have self-organizing and self-management capabilities. From the past, small cells have most typically been used for the purpose of extending overage to indoor or

outdoor areas where signals do not reach very well, or to add network capacity to areas with very dense usage. Small cells provide coverage and capacity in areas which are more difficult or expensive to reach than with traditional macrocells.
As well as being beneficial to wireless network providers, usage of small cells can be extremely beneficial to end-users as well. For one, "5 bar" coverage will be available even in the case of very poor signal coverage in the local area. Along with this, there will be higher mobile data capacity, which could be useful for users without Wi-Fi. Small cells will also allow end-users to have a much better battery life on their mobile devices thanks to reduced transmitter-receiver distance.

4. Summary/Conclusions

Until recent years, mobile networks have been composed of 3G technologies. Fourth Generation technologies are rapidly being developed in order to deal with today's data-hungry mobile users. As LTE continues to grow in the urban sector, small cells will be dispersed geographically to help with load-balancing and inclusion of rural areas. ARCchart estimates that by the year 2017, there will be a total of approximately 5 million small cells shipping annually.
Also, ABI Research estimates that by 2015, approximately 48% of all mobile data traffic will be offloaded from the macro network., and so it should be quite clear that small cells will play a vital role in the Long Term Evolution standard for the foreseeable future.

Resources

[1]http://www.freescale.com/files/wireless_comm/doc/white_paper/LTEPTCLOVWWP.pdf

[2] http://www.lteworld.org

[3] http://www.3gpp.org

[4] V. Srinivasa Rao et. al, Protocol Signaling Procedures in LTE, radisys.