LTE Femto Access Points

One of the major challenges for the next generation wireless communication systems is to improve the indoor coverage and provide high data rate services to the users in a cost-effective manner and at the same time, to enhance network capacity. Additionally, over the next few years, billions of devices will be connected to the Internet and cloud-based applications using 3G and LTE mobile wireless networks, creating tremendous demand for mobile wireless capacity and ubiquitous coverage. The traditional solution would be to increase the number of macro cell sites. It would be difficult to meet this demand, even with 4G technology, by this method as the cost of increased number of base stations (BSs), requirement of spectrum and cost of backhaul wil render the solution uneconomic. In this regard, home base stations, commonly known as femtocells or Femto Access Points (FAPs), are considered as a good option. They improve the network coverage, especially inside houses and in the interiors of buildings and help in providing ubiquitous high speed connectivity to the User Equipment (UE).

In recent years, different types of femtocells have been designed and developed based on various air interface technologies, services, standards, and access control strategies. For example, 3G femtocells use Wideband Code-Division Multiple Access (WCDMA)-based air interface of Universal Mobile Telecommunication System (UMTS), which is also known as UMTS Terrestrial Radio Access (UTRA). The 3rd Generation Partnership Project (3GPP) refers to these 3G femtocells as Home Node Bs (HNBs). On the other hand, WiMAX (Worldwide Interoperability for Microwave Access) and Long Term Evolution (LTE) femtocells use Orthogonal Frequency-Division Multiple Access (OFDMA). The LTE femtocells are referred to as Home evolved Node Bs (HeNBs).

Femtocells are small, short-ranged (10-30 m) low powered (10-100 mW) access points that operate in licensed spectrum and provide mobile coverage and capacity over internet-grade backhaul. They utilize customer's broadband Digital Subscriber Line (DSL) or cable or fiber to the home (FTTH) broadband Internet connections for backhaul to the operator's core network. Femtocells are lower in cost than typical macrocells while retaining full operator management even if they are located on the customer premises.
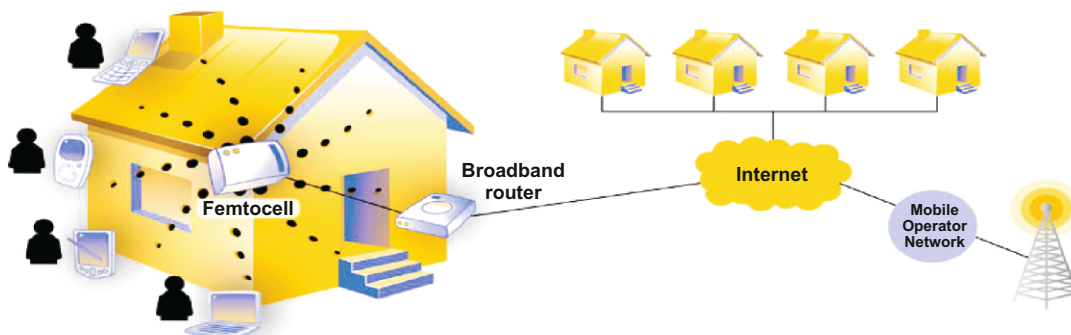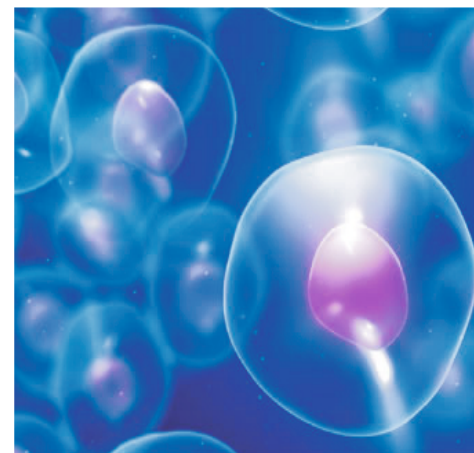

Figure 1 Femtocell network architecture

Femtocells are different from macrocells, microcells, picocells and relays in terms of power, backhaul and access modes as mentioned below :

- Macrocells are conventional base stations with power about 20W, that use dedicated backhaul, are open to public access and range is about 1 km to 20 km.
- Microcells are base stations with power between 1 to 5W, that use dedicated backhaul , are open to public access and range is about 500 m to 2 km.
- Picocells are low power base stations with power ranges from 50 mW to 1 W, that use dedicated backhaul connections , open to public access and range is about is about 200 m or less .
- Femtocells are consumer-deployable base stations that utilize consumer's broadband connection as backhaul , may have restricted association and power is less than 100 mW .
- Relays are base stations using the same spectrum as backhaul and access and has similar power as Picocell.
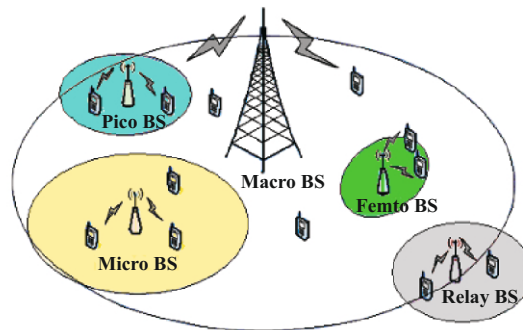

Figure 2 Femtocell as compared to macrocell, microcell, picocell and relay

Advantages of Femtocell

Technical Advantages:
- Low Power: Around 8mW- 120 mW and lower than Wi-Fi Access Points.
- Easy to Use: Plug-and-Play functionality and easily installable by consumers.
- Compatibility & Interoperability: Compatibility with UMTS,EVDO standards and WiMAX, UMB & LTE standards.
- Deployment: In Wireless Operator owned licensed spectrum unlike WiFi.
- Backhaul: User's fixed broadband connection: Such as DSL, cable, or fiber.

Customer's point of view:
- Increased Indoor Coverage: Coverage radius is 40m – 600m in most homes providing full signal throughout the household.
- Load sharing: Unlike in macro cells which supports hundreds of users, Femtos will support 5-7 users simultaneously enabling lesser contention in accessing medium delivering higher data rates/user.
- Better Voice Quality: As the users will be in the coverage envelope and closer to Femtos, they will be supported with a better voice and sound quality with fewer dropped calls.
- Better Data/Multimedia Experience: It will deliver better and higher data performance with streaming music, downloads and web browsing with lesser interruptions compared to a macro-cell environment.
- Femto as a service platform: Novel mobile services can be made available on the femtocell. For example, a femtocell-aware application on the mobile handset could automatically upload photos to a website when the user enters the home.

Wireless Operator's point of view:
- Lower CAPEX: Increased usage of femtocells will cut down huge capital costs on macro cell equipments & deployments. This includes costs savings in site acquisitions, site equipments, site connections with the switching centers.
- Increased network capacity: Increased usage of femtocells will reduce stress on macro cells increasing overall capacity of mobile operators.
- Lower OPEX: With lesser macro cell sites it reduces the overall site maintenance, equipment maintenance and backhaul costs.

- **Newer Revenue Opportunities:** With provision of excellent indoor coverage and superior user experience with voice and multimedia data services operators can generate new revenue streams.
- **Reduced Churn:** Due to improved coverage, user multimedia experience and fewer dropped calls.

Access Modes

Femtocells can operate in one of three following different access modes:
- **Closed access:** In the closed subscriber group (CSG) as defined by the femtocell owner, only a subset of users, defined by the femtocell owner, can connect to the femtocell.This type of femtocell access control strategy is usually applicable in residential deployment scenarios.

- **Open access**: All customers of the operator have the right to make use of any femtocell. This type of femtocell access control strategy is usually applicable in public places such as airports and shopping malls.

- **Hybrid access:** A limited amount of the femtocell resources are available to all users, while the rest are operated in a CSG manner. In small business or enterprise deployment scenarios hybrid access mode of femtocells may be used.

(a) (b) (c)

→ Strong signal
·····▶ Weak signal
→ Strong interference
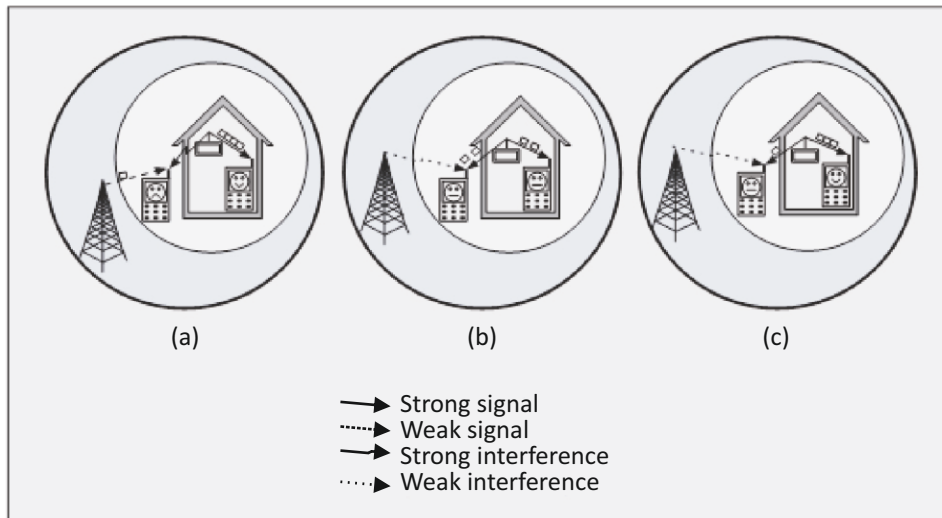·····▶ Weak interference

Figure 3 Access methods: a) closed subscribers group (CSG); b) open access ;c) hybrid access

Architectural Aspects

Since LTE is based on a flat all-IP architecture, the architecture and interfaces are the same for femtocells as for macrocells. LTE femtocells (Home eNodeBs) require no new interfaces to be defined and no changes are required to EPC elements.

There are multiple possible architectures for connecting LTE femtocells to the core network. The Home eNodeB Gateway(HeNB GW), could be used to provide aggregation of multiple Home eNodeBs in the core network.The HeNB GW aggregates S1 interfaces (S1-MME and S1-U), potentially improving the scalability of the core network with respect to femtocells. The communication between the HeNB and the network (HeNB Gateway, when exists, or to the MME) is secured by a mandatory Security Gateway (SeGW) function. Security Gateway may be implemented either as a separate physical entity or co-located with an existing architectural entity.
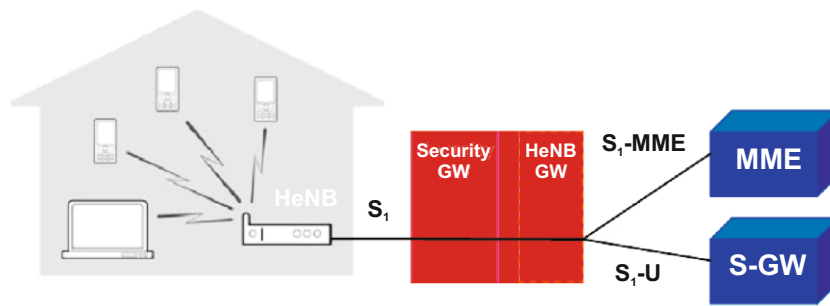
Figure 4 HeNB Architecture and interfaces

There are two variations of the HeNB GW defined, with one aggregating the control plane only while the other aggregates both the control and bearer. Figure 5 shows the architecture where the HeNB GW aggregates both the control and bearer plane traffic and sends the control traffic to the Mobility Management Entity (MME) and the bearer traffic to the Serving Gateway (S-GW).

OMA DM: Open Mobile Alliance Device Management
OTA : Over-the-air programming
VPLMN : Visited Public Land Mobile Network
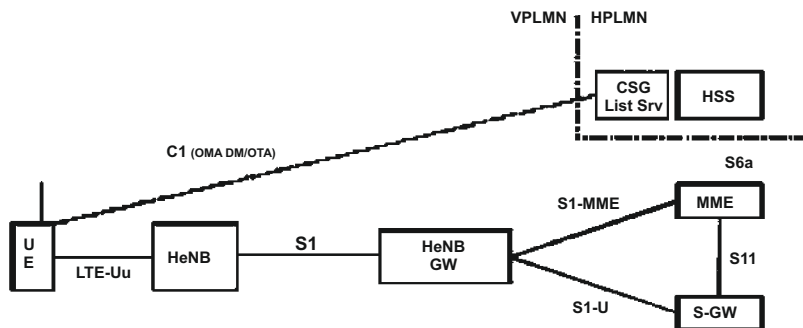HPLMN : Home Public Land Mobile Network
HSS : Home Subscriber Server

Figure 5 HeNB GW aggregates both the control and bearer plane traffic

Figure 6 shows the variant of the architecture where the HeNB GW only aggregates the control plane traffic from multiple HeNBs to the MME.
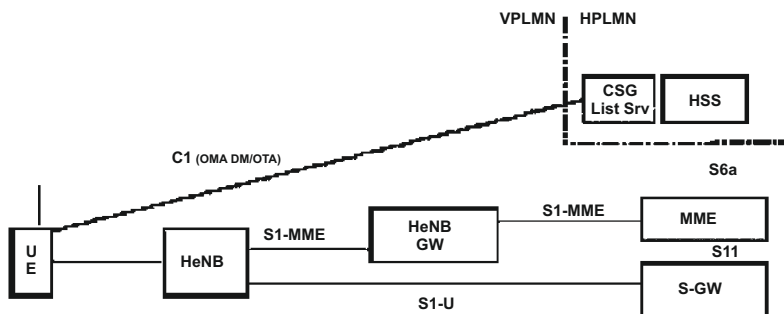

Figure 6 HeNB GW aggregates control plane traffic only

Finally, as stated earlier, the HeNB GW is an optional element and the HeNB can be directly connected to the MME and S-GW (shown in figure 7), assuming that the MME and S-GW have sufficient capacity to support large numbers of femtocell S1 interfaces.
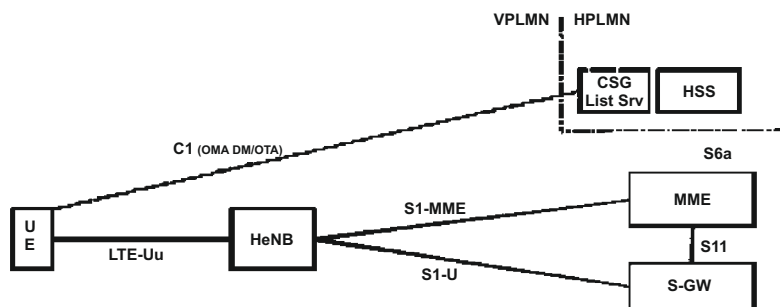

Figure 7 LTE femtocells without HeNB GW

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Technical Challenges in Femtocell deployment

The mass deployment of femtocells gives rise to several technical challenges which are as follows :

RF Interference: In general, two types of interferences occur in a two-tier femtocell network architecture (i.e., a central macrocell is underlaid/overlaid with femtocells)

- Co-tier interference: This type of interference occurs between elements of the same tier, for example, between neighbouring femtocells. It occurs only when the aggressor (or the source of interference) and the victim use the same sub-channels.
- Cross-tier interference: This type of interference is caused by an element of the femtocell tier to the macrocell tier and vice versa. It occurs only when the aggressor (or the source of interference) and the victim use the same sub-channels.
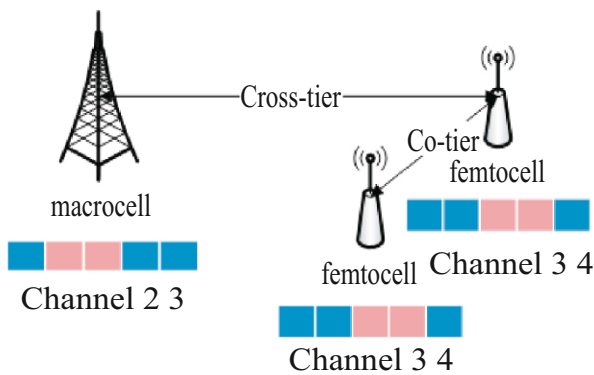

Figure 8 Femtocell interference condition

RF Coverage Optimization: Radio tuning and optimization for RF coverage in macro cells is manually done by technicians which is now not be possible at each femtocell level. Self optimization and tuning over time, according to the indoor coverage map, has to be done either automatically or remotely.

Femto Management: Activation and management of devices by the end user within the household and full visibility into the operation of the femtocell and its surrounding RF environment to first level support technicians must be supported.

Automatic System Selection: When an authorized user of a femtocell moves in or out of the coverage of the femtocell and is not on an active call, the handset must correctly select the system to operate on. In particular, when a user moves from the macro cell into femtocell coverage, the handset must automatically select the femtocell, and visa versa.

Handoffs: When an authorized user of a femtocell moves in or out of coverage of the femtocell and is on an active call, the handset must correctly hand off between the macrocell and femtocell networks. Such handoffs are especially critical when a user loses the coverage of a network that is currently serving it, as in the case of a user leaving the house where a femtocell is located. The common metrics for handover decision mechanism include carrier to Interference-and-Noise Ratio (CINR), Receive Signal Strength Indicator (RSSI) and Quality of Service (QoS). However, those metrics are quite demanding to deal with advanced handover requirement, for instance the fast handover in femtocell network that consist hundreds of possible target FAP.

Timing and synchronization: Timing and frequency stability is critical for femtocells as for operation of macrocells. These necessities are different based on the technology used by a femtocell to access the telecom infrastructure. Synchronization is one of the key issues for femtocellular network because of the Gateway and Clock server communicates to the femtocells via a public backhaul broadband connection. Synchronization is a curtail process in the cellular communication, which is required to mitigate the inter carrier interference (ICI) arising from a carrier offset which causes loss of subcarrier orthogonality and frequency error. In addition, femtocells require an accurate reference for coordinating the absolute phases for forward and reverse link transmissions and bounding the timing drift.

Synchronization options include Timing over Packet, Global Positioning System/Global Navigation Satellite Systems (GPS/GNSS), and network listening over the air. Each has its advantages and drawbacks: The GPS signal may not penetrate indoors. Legacy xDSL or xPON devices may not support IEEE1588 V2 protocol processing. The macro BTS signal may not reach the indoor femtocell. The cost of supporting all these modes is prohibitive, so one should serve as the main method, say 1588-V2 and another such as GPS or network listening as the backup.

Security: Since femtocells could be vulnerable to malicious attacks enhanced authentication and key agreement mechanisms are required to secure femtocell networks. Security risks jeopardize the local femtocell as well as the network connected via public backhaul. These threats include:

- Attacks from the Internet directed against the FAP.
- Subscribers who compromise the FAP to snoop out others or invade the network.
- Entities masquerading as an FAP to strike out against the network.
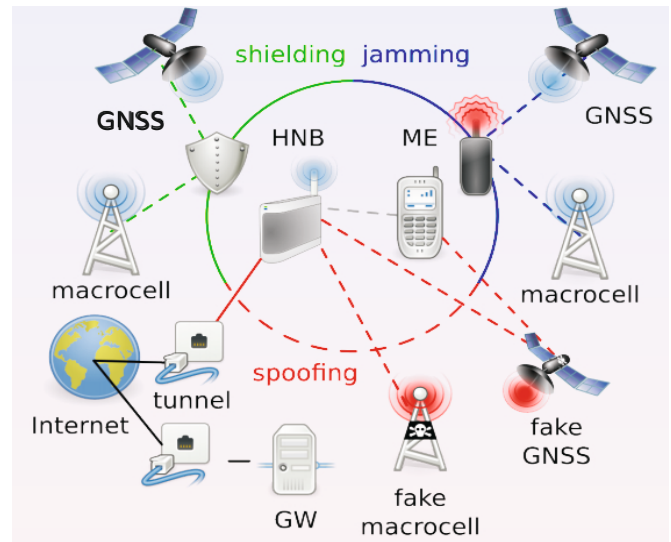
Figure 9 Attacks on the femtocell

Many counter measures protect the femtocells and the network. The service provider can limit access to the FAP, for example, by using a closed subscriber group (CSG) list. FAPs may be locked to prevent access from unregistered locations and authenticated with public key certificates. Internet Protocol Security (IPSec) can protect S1 and OAM (Operation, Administration and Maintenance) traffic, creating the platform for a trusted.

Figure 10 LTE femto security in action

Spectrum: A limited license operator-owned spectrum band has to be shared among femtocells and macrocells. At the top level of the resource allocation process, we have to fix the basic outline : which spectrum bands are available to which base stations classes : either femtocell or macrocell. Three spectrum arrangement structures are identified:

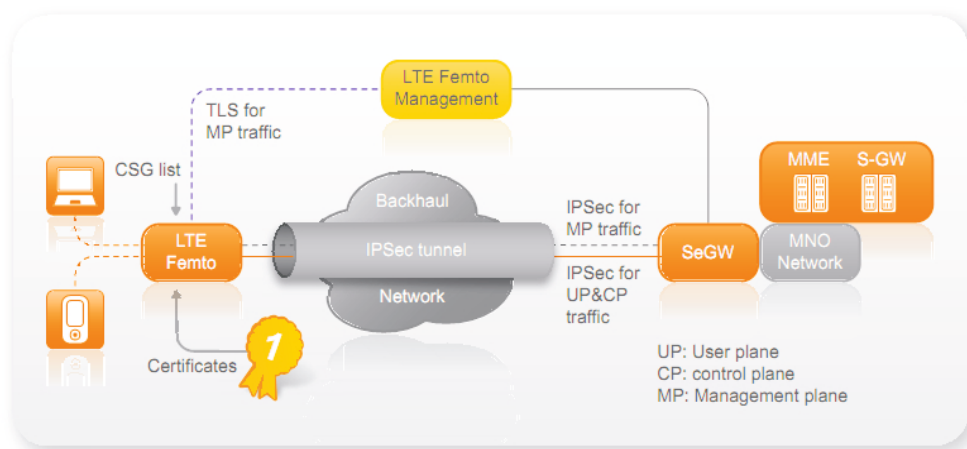1) Complete separation: Femtocells and macrocells use separate spectrum bands. Operating on disjoint bands, femto- and macrocells do not interfere to each other. However, in this case, the transmission band is limited.

2) Partial sharing: Part of the total band can be shared by femtocells and macrocells. The rest of the band is used exclusively by macro or femto cells.

3) Complete sharing: The whole band is shared by femtocells and macrocells thus increasing opportunities for increased spectrum efficiency. In this case, solutions for mitigating interference are crucial and need to be designed.

LTE-Advanced Femtocells

One of the important LTE Advanced benefits is the ability to take advantage of advanced topology networks; optimized heterogeneous networks with a mix of macrocells with low power nodes such as picocells, femtocells and new relay nodes. Small cells such as pico and femtocells bring the network closer to users and provide a big leap in performance. LTE-Advanced optimizes small cell performance through features such as "Range Expansion" to make the leap even more significant. Range Expansion increases the utilization of small cells to increase overall network capacity.
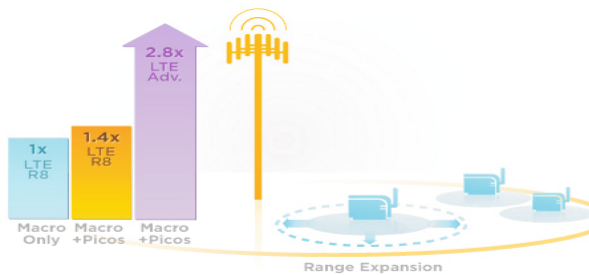

Figure 11 LTE Advanced Femtocell

Top Strategic Technologies for 2012

Mobile-Centric Applications

Extreme Low-Energy Servers

Big Data

In-memory Computing

Next-Generation Analytics

Source : Gartner

3GPP release 10 addresses the support needs of heterogeneous networks that combine low power nodes (such as picocells, femtocells, repeaters, and RNs) within a macrocell. 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.

A support of Local IP access for the HeNB Subsystem was introduced in release 9 but certain features were not completed as part of Rel-9 and the work was moved to Rel-10. Local IP Access provides access for IP capable UEs connected via HeNB (i.e. using HeNB radio access) to other IP capable entities in the same residential/enterprise IP network, including multicast traffic (e.g. discovery protocols) (Figure 12). Data traffic for Local IP Access is expected to not traverse the mobile operator's network except mobile operator network components in the residential/enterprise premises. Signaling traffic will continue to traverse the mobile operator network. The residential/enterprise IP network itself and the entities within that network are not within the scope of 3GPP standardization.

Figure 12 Residential IP Network Connected to a HeNB

HYBRID NETWORKING

There is a wide consensus among service providers, operators, equipment vendors, and academics that the next decade will see highly evolving Internet and network transport architectures. Both circuit and packet switching technologies will be used in hybrid networks that will offer both IP packet and dynamic circuit services. A variety of switching technologies, such as multiprotocol label switching (MPLS), carrier Ethernet based switching, and wavelength-division multiplexed (WDM) optical switching, will be used to offer dynamic (virtual) circuit services, while IP routers will continue to be used for IP packet services. Integrated systems that offer both IP-layer forwarding and MPLS switching, or other combinations, will be used in these hybrid networks.

3GPP Release 10 commercial deployments are expected by 2013, Release 11 that will take up enhancements of LTE-Advanced is expected to be finalised by December 2012 and commercial deployments may take place by 2015.

Figure Hybrid Network

Hybrid network services will no doubt change the ways in which future networks are designed and operated. With the emergence of 100 Gb/s Ethernet, the key question is to deter-mine the optimal level of coordination and integration between packet- and circuit-switched technologies and services. This question will become increasingly important not only for the Internet and telecommunications service providers, but also for data center interconnects, cloud computing systems, and green networks.
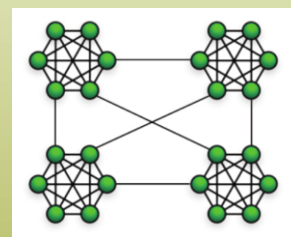
Source : IEEE, 2011

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