CHAPTER TWO

LITERATURE REVIEW

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Literature Review

2.1 Background:

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 (shown in figure 2-1) to the much-anticipated fourth generation technology developed today. [4]

The 4G of wireless cellular systems has been a topic of interest for quite a long time, the first two commercially available technologies billed, as 4G were the Wi-MAX standard (offered in the U.S. by Sprint) and the LTE standard.

2.1.1 Long Term Evolution:

LTE stands for Long Term Evolution and is short for a very technical process for high-speed data for phones and other mobile devices.

By the intensities growth in the user demand six technologies were submitted seeking for approvals international 4G communications standard 3GPP's candidates LTE-Advanced, the backward-compatible enhancement of LTE Release8 (shown in table 2-1) that is fully specified in 3GPP Release10. [5]

By back ward compatibility it is meant that it should be possible to deploy LTE-Advanced in a spectrum already occupied by LTE with no impact on the existing LTE terminals.

Table 2-1 LTE-Advanced Enhancement of Rel.8 LTE

	Uplink/downlink	Rel.8LTE	LTE-Advance
Peak data rate	DL	300Mbps	1Gbps
	UL	75Mbps	500Mbs
Peak spectral efficiency [bps/Hz]	DL	15	30
	UL	3.75	15

2.1.1.1 LTE-Advanced Features:

1. Wider bandwidths, enabled by carrier aggregation.
2. Higher efficiency enabled by enhanced uplink multiple access and enhanced multiple antenna transmission (advanced MIMO techniques).
3. Coordinated multipoint transmission and reception (CoMP).
4. Relaying.
5. Support for heterogeneous networks.
6. LTE self-optimizing network (SON) enhancements.
7. Home enhanced-node-B (HeNB) mobility enhancements.
8. Fixed wireless customer premises equipment (CPE) RF requirements.

[4][6][7]

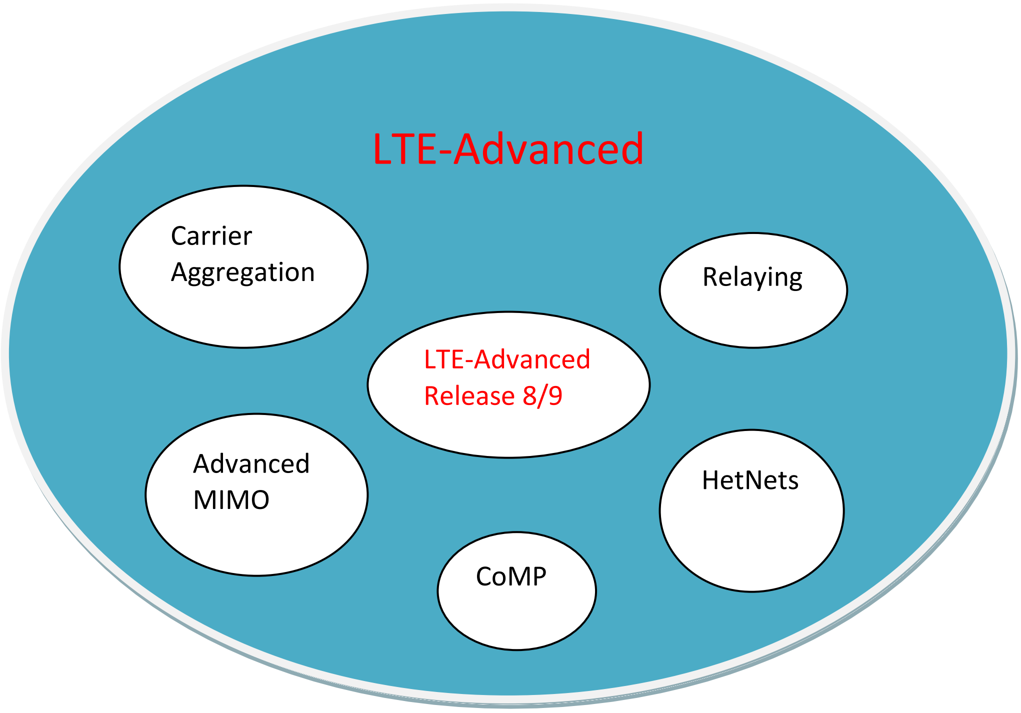

Figure 2-1: LTE-Advanced Key Technologies and Features

- **Carrier Aggregation:**

In order for LTE-Advanced to fully utilize the wider bandwidths of up to 100MHz, while keeping backward compatibility with LTE, a carrier aggregation scheme has been proposed. Carrier aggregation consists of grouping several LTE ‘‘component carriers’’ (CCs) (e.g. of up to 20 MHz). [2]

Because most spectrums are occupied and 100 MHz of contiguous spectrum is not available to most operators, the ITU has allowed the creation of wider band- widths through the aggregation of contiguous and non-contiguous component carriers. Thus, spectrum from one band can be added to spectrum from another band in a UE that supports multiple transceivers.

(IMT-Advanced sets the upper limit at 100 MHz, with 40 MHz the expectation for minimum performance). [4]

- **Multiple Input Multiple Output (MIMO):**

MIMO is a key technique in any modern cellular system that refers to the use of multiple antennas at both the transmitter and receiver sides. It describes the possibility to have multiple Transmitter and receiver antennas. [8]

4G cellular systems will have to provide a large number of users with very high data transmission rates, and MIMO is a very useful tool towards increasing the spectral efficiency of the wireless transmission, adding additional diversity against fading, shaping the overall antenna beam in specific direction and achieving very high Bandwidth utilization without reduction in the power efficiency. [2]

- **LTE Self-Optimizing Network Enhancements:**

Today’s cellular systems are very much centrally planned, and the addition of new nodes to the network involves expensive and time-consuming worksite visits for optimization, and other deployment challenges.

The intent of SON is to substantially reduce the effort required to introduce new nodes and manage the network. There are implications for radio planning as well as for the operations and maintenance (O&M) interface to the base station.

The main aspects of SON can be summarized as follows:

a. Self-configuration: the one-time process of automating a specific event, such as the introduction of a new femto cell, by making use of the O&M interface and the network management module.

b. 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.

c. 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 femto cells.[2][3]

- **Fixed Wireless Customer Premises Equipment (CPE):**

Customer premises equipment in the context of the 3GPP specifications refers to a UE in a fixed location.
The main advantage of the CPE is that it can be optimally located using a higher performance antenna, and it is defined with a higher output power of up to 27dBm compared with 23dBm for a standard UE. [2]

- **Home ENodeBs Mobility Enhancements:**

Another category of network enhancement is the femto cell or home eNodeB (HeNB).Although the femto cell concept is not unique to LTE or LTE-Advanced, An opportunity exists for LTE to incorporate this technology from the start rather than retrospectively designing it into legacy systems such as UMTS and GSM. Operators must decide whether the femto cell will be deployed for closed subscriber group (CSG) UE or for open access. Although in the co-channel CSG case, the probability that areas of dense femto cell deployment will block macro cells becomes an issue. In spite of this issue, studies have shown that increases in average data rates and capacity are possible with femto cells over what can be achieved from the macro network. On the other hand, femto cells do not provide the mobility of macro cellular systems, and differences exist in the use models. For these reasons, femto cell and hotspot deployments should be considered complimentary to rather than competitive with macro cells and microcells. [4]

- **Relaying:**

Another method of improving coverage in difficult conditions is the use of relaying. The main use cases for relays are to improve urban or indoor throughput, to add dead zone coverage, or to extend coverage in rural areas. The concept of relaying is not new but the level of sophistication continues to grow. The most basic and legacy relay method is the use of a radio repeater, which receives, amplifies and then retransmits the downlink and uplink signals to overcome areas of poor coverage.

In general, repeaters can improve coverage but do not substantially increase capacity in order to increase the capacity along with coverage. Release10 intends to address the support of heterogeneous networks Deployment method one of the most LTE-Advanced key technologies. [4]

2.1.2 Homogenous and Heterogeneous Networks:

Traditionally the deployment of cellular mobile network was homogenous deployment (shown in figure 2-2). A homogeneous cellular system is a network of base-stations in a planned layout and a collection of user terminals, in which all the base-stations have similar transmit power levels, antenna patterns, receiver noise floors, and similar backhaul connectivity to the (packet) data network. Moreover, all base stations offer unrestricted access to user terminals in the network, and serve roughly the same number of user terminals, all of which carry similar data flows with similar QoS requirements. [12]

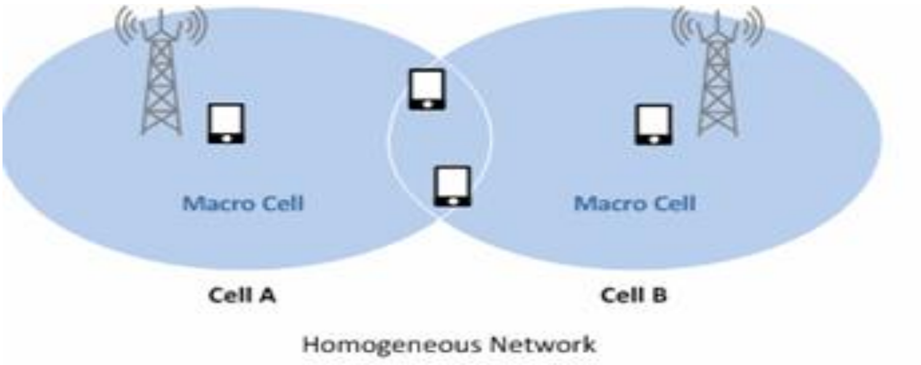

Figure2-2: Homogeneous Network Deployment

The locations of the macro base-stations are carefully chosen by network planers, and the base-station settings are properly configured to maximize the coverage and control the interference between base-stations.

As the traffic demand grows and the RF environment changes, the network relies on cell splitting or additional carriers to overcome capacity and link budget limitations and maintain uniform user experience. However, this deployment process is complex and iterative. Moreover, site acquisition for macro base-stations with towers becomes more difficult in dense urban areas.

A more flexible deployment model is needed for operators to improve broadband user experience in a ubiquitous and cost effective way.

There are several approaches that can be taken to meet traffic and data rate demands on a high level, the key options to expand network capacity include:

1. Improving the macro layer.
2. Densification the macro layer.

3. Complementing the macro layer with low power nodes, thereby creating a heterogeneous network.[9]

Additional frequency resources can increase capacity easily but it is difficult for operators to get them because of the finite nature of the network. [13]

One of the promising and cost-effective approaches to resolve this issue is heterogeneous Networks (HetNet) where Low Power Nodes (LPNs) (e.g. Micro/Pico/Home eNodeB and Relay node) are deployed throughout a Macro cell layout (shown in Figure 2.3). [14]

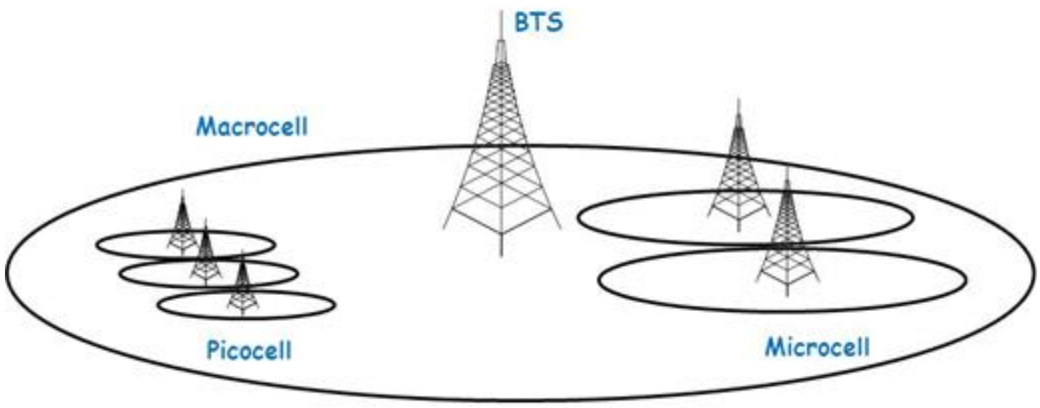

Figure 2.3: Heterogeneous Network Architecture

2.1.2.1 Low Power Nodes (LPNs) Types

- Femto nodes (also called residential femto nodes) are the smallest of low power nodes, providing coverage for a single-family home with 4 to 6 active users.
- Pico nodes (sometimes called enterprise femto nodes) are intended to serve multi-story buildings and campuses, which each pico node handling up to 32 users.

- Micro nodes are generally used in outdoor environments to provide additional coverage and/or capacity to the network, each carrying up to 128 users. Urban micro nodes (as opposed to rural micro cells) are often referred to as metro low power nodes.

  Low power nodes (shown in figure 2-4) usually referred to as small cells.

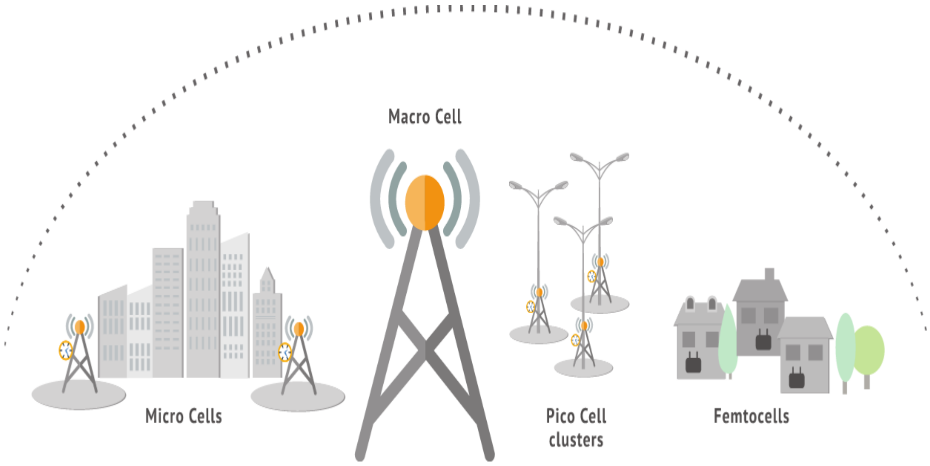

Figure 2-4: LPNs (small cells) Types

The low-power base-stations can be deployed to eliminate coverage holes in the macro-only system and improve capacity in hot spots. While the placement of macro base-stations in a cellular network is generally based on careful network planning, the placement of Pico/relay base-stations may be more or less ad hoc (discussed in 2.1.3.6), based on just a rough knowledge of coverage issues and traffic density (e.g. hotspots) in the network. Due to their lower transmit power and smaller physical size, Pico/femto/relay base-stations (shown in figure 2-5) can offer flexible site acquisitions. Relay base-stations offers additional flexibility in backhaul where wire line backhaul is unavailable or not economical. [12]

Figure (2-5): Commercial Small cells

2.1.2.2 Design Options for Heterogeneous Networks:

Several aspects govern effective design of heterogeneous networks.

- From a demand perspective:

Traffic volumes, traffic location and target data rates are important.

- From a supply perspective:

The important aspects include radio environment, macro-cellular coverage, site availability, backhaul transmission, spectrum and integration with the existing macro network

- Commercial aspects:

Such as technology competition, business models, and marketing and pricing strategies must also be considered. [11]

In the network-design process, it is important to consider the business model. While a single operator often manages outdoor macro-cellular networks in urban areas.

Indoor systems are often shared between operators (Distributed Antenna Systems). Wi-Fi access points and similar smaller scale solutions are often user-deployed (by individuals, enterprises or a third party), where access can be open for all subscribers or available for certain users only (Closed Subscriber Group). [9]

The major benefit enterprises glean from the heterogeneous hypervisor approach is usually financial savings (discussed in 2.1.3.1).

2.1.2.3 Advantages to Heterogeneity:

Different platforms and operating systems have different characteristics and one may be better suited to a particular task. Having systems running many different operating systems gives users access to a wider range of application software.

On the other hand, learning best practices for locking down one OS can be difficult enough, without having to learn what you need to do for several different operating systems. And because all those different systems need to communicate with one another, the security settings in heterogeneous environments have both advantages and disadvantages

When it comes to security network can conflict, resulting in needed resources being rendered inaccessible. While the diversity of device types, operating systems and applications lower the risk of all users being affected simultaneously by an attack or malware, it also increases the security overhead for administrators and complicates the process of applying standard security measures. Like it or not, however, the heterogeneous network is here to stay and will likely grow even more diversified as time goes on, so it’s important for IT pros to familiarize themselves with the common security challenges created by this trend and with the solutions that are being developed to address those challenges.

flexible Heterogeneous networks techniques adopted as the most pragmatic, scalable and cost-effective means to significantly enhance the capacity of today's mobile wireless networks by inserting smaller, cheaper, self-configurable base-stations and relays in an unplanned, incremental manner into the existing macro cellular networks.[12]

As mentioned before Macro cellular systems have reached maturity and operators in many countries are reaching the maximum price/performance benefit for this type of infrastructure within their cellular networks. 'Small cells' are the best answer to smaller area coverage and capacity requirements, but also come with particular challenges that must be addressed.

Small cells provide a solution that can cover smaller areas than macro cell networks. They also use lower-power radios and their smaller form factors ease installation.

2.1.3 Heterogonous Networks Small Cells:

Small cells which are low-power wireless access points that operate in licensed spectrum are operator-managed and feature edge-based intelligence." [17]

- The key points here are:

1. **Low Power**: Small cells operate at significantly lower power levels than normal base stations. Where a typical cellular base station might broadcast with 40 Watts of power, a small cell may transmit at only 50 mille Watts, depending on the particular environment.
2. **Licensed Spectrum**: Small cells use the same spectrum and radio technologies as the mobile wireless network they're associated

with, allowing a more seamless integration with the macro network and a more consistent user experience.

3. **Operator Managed**: Although a small cell may be physically deployed by the end user, it is still considered to be part of the operator's network, so that it can be configured and managed along with the other cells in the network.

This definition leaves out things like Wi-Fi access points, which use unlicensed spectrum and are usually managed by the individuals or businesses that bought then. [17]

2.1.3.1 Small Cell Benefits:

So what can a small cell do that a macro cell can't do? The short answer is: nothing. Small cells can do everything that big cells can do, except cover a lot of territory and serve a lot of users. The value of a small cell is not its horsepower, but its economy. If the operator needs to add additional capacity in a particular location, or fill in a coverage hole, a small cell can often do the job for a fraction of the cost.

- **This cost benefits comes from a number of factors:**

1. **Lower Equipment Costs**: Because they are physically smaller and much more integrated than macro cells, a small cell may cost hundreds of dollars rather than tens of thousands.
2. **Lower Real Estate Costs**: Small cells are often hung on the walls or bolted to lamp posts (shown in figure 2-6), eliminating the need to acquire floor space or build enclosures. Even the larger microcells have a smaller footprint than traditional macro cells.
3. **Plug and Play**: Small cells are designed to simplify the deployment effort, allowing the cell to be connected to the

network and configured with little or no manual intervention. Coordination with the rest of the network is handled by the operator's automated management systems, further reducing ongoing operational costs.

Figure (2-6): small cell installed in a lamp

The end result is a suite of economical solutions that the operator can deploy (shown Figure 2-4). To handle a wide variety of opportunities, including (but not limited to):

1. Improving in-home coverage and performance (residential femto cells)
2. Covering campus and corporate environments (enterprise femto cells and Pico cells).
3. Filling in coverage holes, offloading macro cells and adding additional "hot spot" capacity (urban microcells and metro cells)

4. Serving remote areas that would otherwise not have service (rural microcells).

2.1.3.2 Capacity and Coverage Deployment Styles:

The use cases differentiate between small cells providing capacity and those providing coverage (sown in figure 2-7). However adding a small cell to the network provides a degree of both, so what's the difference?

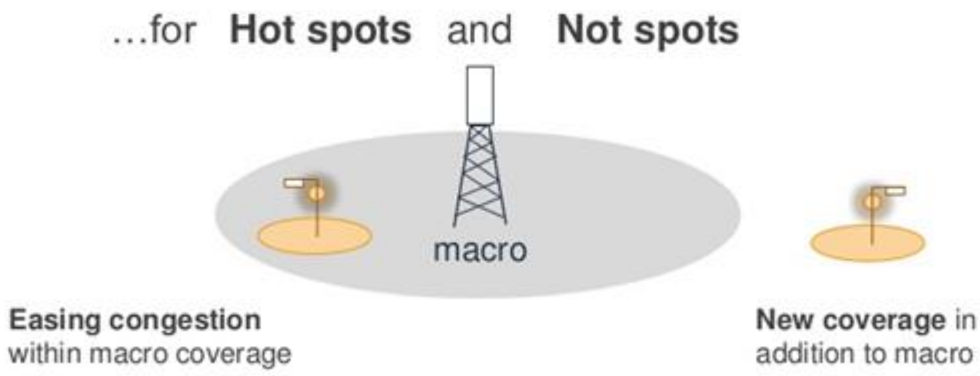

Figure 2-7: Heterogonous Deployment Styles

Considering whether the small cell is deployed in addition to existing macro coverage, or whether it brings a new service to an area where it was previously unavailable. In the days of voice, the service is either there or not. However in the age of mobile data the 'service' can range from GSM EDGE with a few kbps, to multi-megabit HSPA or LTE.

A general definition is that coverage enhancement brings a new service (or level of service) to an area where it could not previously be experienced, even during quiet times with only one user accessing the network. [17]

Capacity enhancement can be considered as a way of increasing the number of people that can have a given level of broadband experience in an area during the busy times. Although a small cell will likely improve both coverage and capacity, the definitions consider the operators primary motivation for deployment. [17]

For example taking in-building 'hot spot' traffic (shopping malls, train stations and entertainment venues) off the macro cell network via a small cell solution can potentially remove up to 32% of the network traffic carried by macro cells. Event-driven sites such as stadiums present further opportunities: BT was reported to have hit a peak when it carried 6.7GB of data per second through its Wi-Fi network during the London 2012 Olympic Games and AT&T reported a high of 78GB of cellular traffic during the 2013 Super Bowl half-time show and the 35-minute power outage that followed. This traffic would overwhelm the typical cellular network, but small cells can support cellular and/or Wi-Fi to provide both highly localized and even portable (cells on wheels) capacity and coverage. [18]

2.1.3.3 Deploying and Operating Small Cells Challenges:

When mobile operators deploy small cells, they often find that they do not deliver the expected user experience. A primary reason for degraded quality of service with heterogonous networks is poor cell-edge performance due to the lack of traffic coordination and interference management between small cells and macro cells. [19]

The small cell banner incorporates micro, Pico, femto and metro cells which are collectively expected to constitute almost 90% of all base stations by 2016. [20]

However, significant challenges remain in deploying small cells, connecting them up and switching them on. A recent survey found 56% of operators citing backhaul as one of the greatest challenges, second only to fundamental issues of site acquisition, power etc[21]

The challenges can be summarized as follow:

- **The Costs of a Small Cell Hardware System**

The costs of a small cell hardware system are not small; operators expect costs for new small cell hardware to decline by 60–75% within the next two years to a price point that is expected to be one-fifth the price of a macro cell system. We believe that price targets will be met because:

a. Major operators such as AT&T (USA), SK Telecom (South Korea), Sprint (USA), Telephonic (Spain) and Telenor (Norway) are committed to ordering large volumes.
b. Progress with system-on-a-chip (SOC) components is decreasing the costs of small cell electronics.
c. The presence of multiple vendors including Airspan, Alcatel-Lucent, Cisco Systems, Ericsson, Ruckus Wireless and Spider Cloud Wireless will create a highly competitive environment.

1. **Installation Complexity and Operational Costs**

Small size does not mean lower installation complexity or reduced operational costs, operating tens of thousands of small cells increases both installation and operational costs. Simplified installation capabilities such as self-organizing/optimizing network (SON) features – including automatic neighbor identification and radio optimization – are needed in order to reduce the time required for each installation to a matter of hours, from up to 6 months for a macro site installation. Vendors are promoting SON as the best solution to reduce complexity and operational costs (by up to 80%), and to mitigate macro network interference

2. **Operators Strategies for Designing**

Operators are starting to pursue their small cell strategies, small cells change how operators will design cellular networks and, therefore, must be factored in to all 3G and 4G cellular network upgrade and deployment strategies. [22]

2.1.3.4 Small cell access policies:

- **Closed access:**

Only registered users belonging to a closed subscriber group (CSG) can connect.

Potential interference from loud (macro UE) neighbors.

- **Open access:**

All users connect to the small cells (pico/metro/microcells)

Alleviate interference but needs incentives for user to share their access.

- **Hybrid access:**

All users + priority to a fixed number of femto users.

Subject to cost constants and backhaul conditions.

Femto cells are generally closed, open or hybrid access.

Pico cells are usually open access by nature and used for offloading. Macro cell traffic and achieving cell splitting gains.

2.1.3.5 Small cell deployments strategies

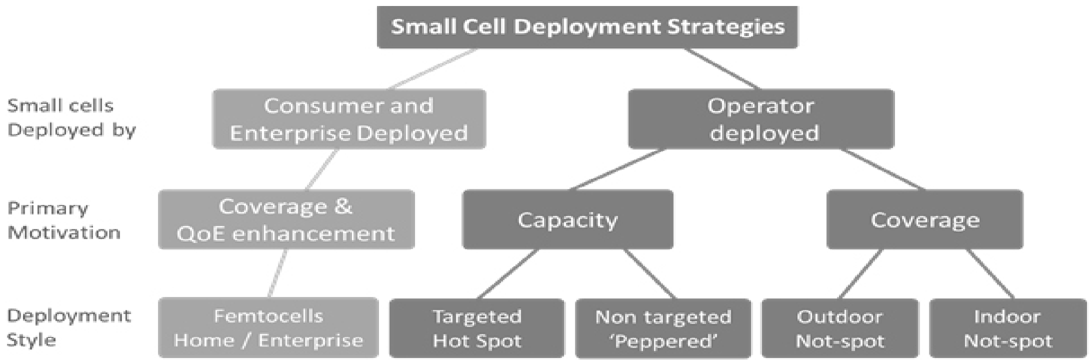

Figure (2-8): Small cell deployments strategies

Deployment styles were grouped (shown in figure 2-8) into broad use case categories defining the primary motivation and style of deployment as follows:

1. Consumer/Enterprise self-deployed (femto cells)
2. Operator deployed small cells:

a. Targeted capacity hot-spot
b. Non targeted ('peppered') Quality of Experience (QoE) enhancement
c. Outdoor and indoor coverage not-spots

- **Consumer/Enterprise Self-Deployed (femto cells)**

The vast majority of small cells will be self-deployed by consumers or enterprises in order to provide coverage or enhance the QoS of cellular connectivity in their home or office. Femto cells or 'home base stations' have required the development of true plug and play technologies, as well as those for Self Organizing Networks (SONs). End users deploy the small cell where they believe it is most needed and where they can provide power and network connectivity.

Self-deployed residential and enterprise femto cells typically use leased internet connections for backhaul. A key limitation of self-deployed femto cells is that most consumers would prefer to restrict access to themselves and a limited ‘white list’ of users. These ‘closed access’ small cells therefore do not improve coverage for all of an operator’s subscribers. As such, operators are looking to leverage the benefits of femto cell technologies for low-cost deployment, but in an ‘open access’ mode available to all subscribers.

- **Operator Deployed Small Cells**
    a. **Targeted Capacity Hot-spot:**

The small cell is deployed at the Centre of an area of high-demand density. Macro coverage is already present at the location, but hot-spot demand causes congestion and poor Quality of Service (QoS) during busy times. The hotspot small cell provides both better propagation and less sharing of the mobile spectrum, improving QoS for the users it serves. Offloading this traffic also improves QoS for users who continue to be served by the macro layer. Hot-spot deployment requires identification of the high-demand locations, and for them not to move during the lifetime of the small cell. Data mining techniques based on social media (e.g. geo-tags from Flicker photos or tweets) can indicate concentration of Smartphone usage and potential capacity hot-spots. Targeted hot-spot deployment further requires that a site can be acquired close enough to the optimal location for the small cell’s coverage to match with the area of high demand. Because the coverage area of a small cell is, by definition, small, this may be very difficult to achieve in practice. Demand hot-spots can potentially be located from geo-tagged social media data source

b. Non-Targeted ('Peppered') QoE Enhancement:

The 'peppered' approach deploys many small cells in areas of high demand for general enhancement of consumer QoE over existing underlay macro coverage. Site selection is less focused on pinpointing the perfect locations, and instead makes use of available sites which can easily be acquired and backhauled. It is more suited to areas of high-demand significantly larger than the coverage area of a single small cell.

Although in theory 'peppered' is likely to be marginally less efficient than a targeted approach, in practice the difficulties in pinpointing long-term hotspots and acquiring optimal site locations with backhaul will erode the benefits.

c. Outdoor and Indoor Coverage :

Small cells can be deployed in areas with no existing macro coverage often called 'not-spots'. These may be isolated locales where it is not cost-effective to deploy a macro-site, but a lower cost small cell would suffice. They might also be large indoor areas in public buildings such as shopping malls or airports cells may help operators extend coverage to the last few per-cent of the population, both outdoors and indoors.

-Potential outdoor and indoor not-spots

Outdoor

- Underserved villages and town locations.

Indoor

- Rural areas with marginal outdoor coverage.
- Shopping malls, airports, museums.
- 'On board' a ferry, train or airplane.

Privately owned homes and businesses needing coverage might be better suited to a self-deployed ‘femto cell’ approach. [20]

2.1.3.6 Cell Selection:

Cell selection is based on the downlink received signal strength (discussed in chapter 3) which means mobile users will connect to the site from which the received power is strongest.

2.2 Related works:

The recent works demonstrated the benefits of Pico cell range expansion. However, they lack a parametric study or systematic design for Pico cell range expansion.

The authors in [43] discussed the need for an alternative deployment model and topology using heterogeneous networks. To enhance the performance of these networks, advanced techniques are described; Range expansion allows more user terminals to benefit directly from low-power base stations such as Picos, femtos and relays. The performance gains possible via heterogeneous networks were shown using a macro/Pico network example.

The simulation of [43] showed that the sum rate can improve both cell-median and cell-edge UEs in a HetNet by connecting UEs to the cells with the lowest path-loss. However, associating many UEs to a Pico cell by a large range expansion bias (REB) may cause overload issues.

In paper [44] the authors developed a tractable framework for SINR analysis in downlink heterogeneous cellular networks (HCNs) with flexible cell association. The HCN is modeled as a multi-tier cellular network where each tier's base stations (BSs) are randomly located and have a unique transmit power, path loss exponent, spatial density, and bias towards admitting users. They implicitly assumed every BS has full queues. The outage probability of a typical user in the network which can be viewed as a spatial average of SINR over all users in the network. has been derived as a function of (REB) using homogeneous Poisson point processes (PPPs) to model the locations of MBSs and PBSs the observed was that deploying more or less BSs does not change the outage probability in interference-limited HCN with unbiased cell association, and observed how biasing affects the metric.

Also using PPP models, spectral efficiencies in range expanded Pico cell networks have been analyzed in [45].

Analytical models were consider for base station and UEs locations in a macro network with Pico-cell overlay and derived closed-form expressions for the distribution of the signal to interference plus noise ratio (SINR) and spectral efficiencies (SEs) of UEs associated with macro- and Pico-cells. These results illuminate the effects on SE of (i) duration of the macro almost blank sub frames (ABSs), (ii) the SINR threshold for a UE to be served by a Pico cell during ABSs, and (iii) the range expansion bias. They also help determine the optimum settings of these parameters. [45]

And also in [46] a related spectral efficiency analysis was studied. Off-loading benefits of range expansion in heterogonous networks are captured through cumulative distribution functions (CDFs) of the downlink signal to interference plus noise ratio (SINR) difference between the macro cell and strongest Pico cell signals. Then, these CDFs are used to investigate the system capacity and fairness as a continuous function of the range expansion bias.

[47] investigates three cell selection methods associated with ICIC in heterogeneous networks in the LTE-Advanced downlink: signal-to-interference plus noise power ratio (SINR)-based cell selection, reference signal received power (RSRP)-based cell selection, and reference signal received quality (RSRQ)-based cell selection.

Simulation results (4 Pico eNodeBs and 25 set of user equipment are uniformly located within 1 macro eNodeB) assuming full buffer model show that the downlink cell and cell-edge user throughput levels of RSRP-based cell selection are degraded by approximately 3% and 10% compared to those of SINR-based cell selection under the condition of the maximizing the cell-edge user throughput due to the impairment of

the interference level. Furthermore, it is shown that the downlink cell-edge user throughput of RSRQ-based cell selection is improved approximately 5%, although the cell throughput is degraded approximately 5% compared to that for SINR-based cell selection under the condition of the maximizing the cell-edge user throughput. [16]
The performance of range expansion in conjunction was evaluated with ICIC for randomly selected REBs such as (8-16) dB, while details of the ICIC scheme were missing.

In [16] the authors combined a range expansion with a resource partitioning (RP)-based ICIC, where the available spectrum was divided between Macro cells and Pico cells so that extend range PUEs were protected from Macro cell DL interference. On the other hand, RP lowers spectral efficiency, since resources accessed by Macro cells cannot be reused by Pico cells.

System simulations results for an FTP traffic model indicate that, for a Pico cell deployment with density of 4 Picos per macro cell, 40% or more performance gain can be achieved when techniques enabling cell range expansion are deployed.