Analysis And Comparison Between Performance Parameters Of Small Cells And Femtocells In Long Term Evolution (LTE)

A dissertation submitted in partial fulfillment of requirement for the degree of Bachelor of Science in Engineering in Electrical and Electronic Engineering

Islamic University Of Technology (IUT)

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This is to certify that the work presented in this thesis is an outcome of the experiments, study, simulation and real time work carried out by the authors under the supervision of Mohammad Tawhid Kawser, Assistant Professor, Electrical and Electronic Engineering Department, Islamic University of Technology (IUT), OIC.

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Analysis And Comparison Between Performance Parameters Of Small Cells And Femtocells In Long Term Evolution (LTE)

ABSTRACT

LTE, short for **Long Term Evolution**, is considered by many to be the obvious successor to the current generation of **UMTS 3G technology. Small Cells** in **LTE** are currently being used widely because of their many advantages. As high-rise buildings and street canyons cause coverage holes in certain parts of the topology and high user densities also cause the capacity of macro cells to be exhausted, placing small cells at strategic points in these areas helps to overcome coverage and capacity problems. Small cells are low-cost alternative to macro cells in rural and hard-to-reach areas because of their ease of installation. On the other hand, **Femtocells** also provide the best solution for seamless, transparent offload and ubiquitous coverage for high-speed data. So, by using Vienna Simulator, the performance parameters of **Small Cells** and **Femtocells** are compared to conclude which type of cells is best suited for overpopulated and dense urban places.

List of Acronyms

1xEV-DO	1x Evolution for Data Optimized
3GPP	Third Generation Partnership Project
3GPP2	Third Generation Partnership Project 2
4G	Fourth Generation Wireless Systems
AAA	Authentication, Authorization and Accounting
AAS	Adaptive Antenna System
AC	Authentication Center
ACK	Acknowledge or Acknowledgement
AM	Acknowledged Mode
AMBR	Aggregate Maximum Bit Rate
AMC	Adaptive Modulation and Coding
AN	Access Network
APN	Access Point Name
ARP	Address Resolution Protocol
ARP	Allocation and Retention Priority
ARQ	Automatic Repeat reQuest
AS	Access Stratum
AS	Application Server
BCCH	Broadcast Control Channel
BCH	Broadcast Channel
BER	Bit Error Rate
BLER	Block Error Rate
BPSK	Binary Phase Shift Keying
BW	Bandwidth
C-RNTI	Cell Radio Network Temporary Identity
CDMA	Code Division Multiple Access
CE	Cyclic Extension
CFI	Channel Format Indicator
CN	Core Network
CoA	Care Of Address
CP	Cyclic Prefix
CQI	Channel Quality Indicator
CRC	Cyclic Redundancy Check
CS	Circuit-Switched
CS-CN	Circuit Switched Core Network
CSCF	Call Session Control Function
CSI	Channel State Information
DCCH	Dedicated Control Channel
DCI	Downlink Control Information
DFT	Discrete Fourier Transform
DHCP	Dynamic Host Configuration Protocol
DL	Downlink
DL-SCH	Downlink Shared Channel
DRA	Dynamic Resource Allocation
DRX	Discontinuous Reception
DS	Direct Spread
DSCP	Differentiated Service Code Point
DTCH	Dedicated Traffic Channel
DTX	Discontinuous Transmission
E-UTRA	Evolved UMTS Terrestrial Radio Access
E-UTRAN	Evolved UMTS Terrestrial Radio Access Network
ECM	EPS Connection Management
eNB	E-UTRAN Node B
EMM	EPS Mobility Management
EPC	Evolved Packet Core
EPS	Evolved Packet System
ESP	Encapsulating Security Payload
EUTRAN	Evolved UTRAN
EV-DO	Evolution for Data Optimized
FA	Foreign Agent
FDD	Frequency Division Duplex
FDM	Frequency Division Multiplexing
FDMA	Frequency Division Multiple Access
FEC	Forward Error Correction
FFT	Fast Fourier Transform
FMC	Fixed Mobile Convergence
GBR	Guaranteed Bit Rate
GGSN	Gateway GPRS Support Node
GI	Guard Interval
GP	Guard Period
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communication
GUTI	Globally unique Temporary UE identity
GUMMEI	Globally Unique MME Identity
GT	Guard Time
GTP	GPRS Tunneling Protocol
GTP-U	GTP User plane
GW	Gateway
DRX	Discontinuous Reception
DS	Direct Spread
DSCP	Differentiated Service Code Point
DTCH	Dedicated Traffic Channel
DTX	Discontinuous Transmission
E-UTRA	Evolved UMTS Terrestrial Radio Access
E-UTRAN	Evolved UMTS Terrestrial Radio Access Network
ECM	EPS Connection Management
eNB	E-UTRAN Node B
EMM	EPS Mobility Management

EPC	Evolved Packet Core
EPS	Evolved Packet System
ESP	Encapsulating Security Payload
EUTRAN	Evolved UTRAN
EV-DO	Evolution for Data Optimized
FA	Foreign Agent
FDD	Frequency Division Duplex
FDM	Frequency Division Multiplexing
FDMA	Frequency Division Multiple Access
FEC	Forward Error Correction
FFT	Fast Fourier Transform
FMC	Fixed Mobile Convergence
GBR	Guaranteed Bit Rate
GGSN	Gateway GPRS Support Node
GI	Guard Interval
GP	Guard Period
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communication
GUTI	Globally unique Temporary UE identity
GUMMEI	Globally Unique MME Identity
GT	Guard Time
GTP	GPRS Tunneling Protocol
GTP-U	GTP User plane
GW	Gateway
H-FDD	Half-Frequency Division Duplex
HA	Home Agent
H-ARQ	Hybrid ARQ
HDTV	Hi Definition TV
HLR	Home Location Register
HO	Handover
HPLMN	Home PLMN
HSDPA	High Speed Downlink Packet Access
HSPA	High Speed Packet Access
HSS	Home Subscriber Server
HSUPA	High Speed Uplink Packet Access
ICI	Inter-Carrier Interference
ICIC	Inter-cell Interference Coordination
IDFT	Inverse Discrete Fourier Transform
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IFFT	Inverse Fast Fourier Transform
IMEI	International Mobile Equipment Identity
IMS	IP Multimedia Subsystem
IMSI	International Mobile Subscriber Identity
IMT	International Mobile Telecommunication
IN	Intelligent Networks
IP	Internet Protocol
IPSec	Internet Protocol Security
IPv4	Internet Protocol version 4
ISI	Inter-Symbol Interference
ISUP	ISDN Signaling User Part
ITU	International Telecommunication Union
kbps	kilo-bits per second
KHz	Kilo Hertz
L1	Layer 1 (physical layer)
L3	Layer 3 (network layer)
LB	Load Balancing
LCR	Low Chip Rate
LI	Lawful Intercept
LTE	Long Term Evolution
MAC	Medium Access Control
MAC	Message Authentication Code
MBMS	Multimedia Broadcast Multicast Service
MBR	Maximum Bit Rate
MBSFN	MBMS Single Frequency Network
MCCH	Multicast Control Channel
MCH	Multicast Channel
MCM	Multi-Carrier Modulation
ME	Mobile Equipment
MGCF	Media Gateway Control Function
MGW	Media Gateway
MHz	Mega Hertz
MIB	Master Information Block
MIMO	Multiple Input Multiple Output
MIP	Mobile IP
MISO	Multiple Input Single Output
MMD	Multimedia Domain
MME	Mobility Management Entity
MMEGI	MME Group Identity
MMS	Multimedia Messaging Service
MS	Mobile Station
MSC	Mobile Switching Center
MTCH	MBMS Traffic Channel
NACK	Negative ACK
NAS	Non-Access Stratum
NBM	Network Based Mobility
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
OSS	Operations System Support
P-GW	PDN Gateway
P-SCH	Primary Synchronization Channel
PAPR	Peak-to-Average Power Ratio
PBCH	Physical Broadcast Channel
PCCH	Paging Control Channel
PCH	Paging Channel
PCFICH	Physical Control Format Indicator Channel

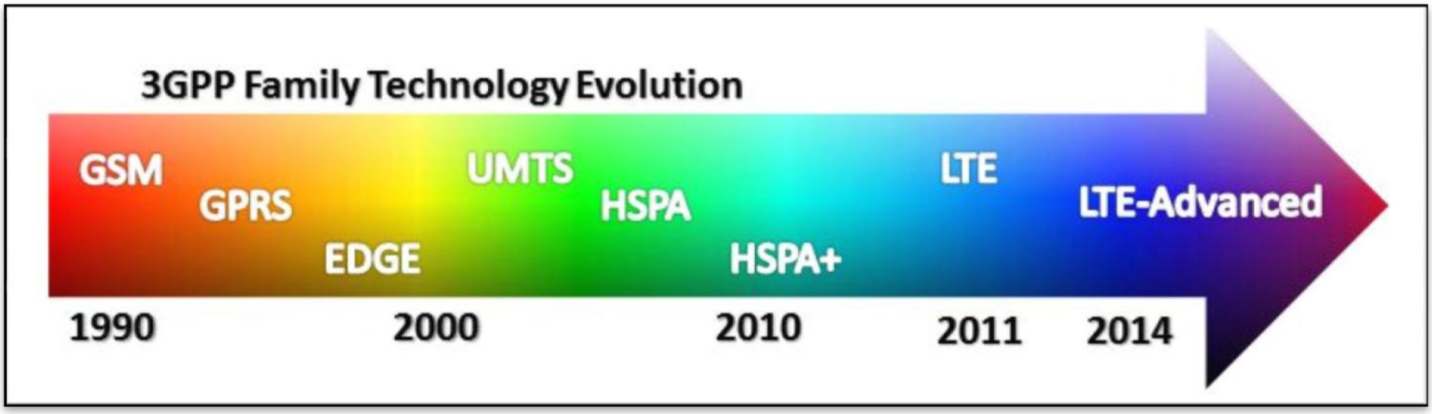
PDP	Policy Decision Point
PDSCH	Physical Downlink Shared Channel
PDU	Protocol Data Unit
PHICH	Physical Hybrid ARQ Indicator Channel
PHY	Physical Layer
PLMN	Public Land Mobile Network
PMCH	Physical Multicast Channel
PMIP	Proxy MIP
PN	Pseudo-random Noise
PRACH	Physical Random Access Channel
PRB	Physical Resource Block
PRI	Primary Rate Interface
P-RNTI	Paging Radio Network Temporary Identity
PSDU	Protocol Service Data Unit
PSTN	Public Switched Telephone Network
PUCCH	Physical Uplink Control Channel
PUSCH	Physical Uplink Shared Channel
QAM	Quadrature Amplitude Modulation
QCI	QoS Class Identifiers
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RACH	Random Access Channel
RAN	Radio Access Network
RAT	Radio Access Technology
RB	Radio Bearer
RB	Resource Block
RF	Radio Frequency
RLC	Radio Link Control
ROCH	Robust Header Compression
RRC	Radio Resource Control
RRM	Radio Resource Management
RSRP	Reference Symbol Received Power
RSSI	Received Signal Strength Indicator
S-GW	Serving Gateway
S1-U	S1 - User Plane
SAE	System Architecture Evolution
SC	Single Carrier
SC-FDMA	Single Carrier - Frequency Division Multiple Access
SCH	Synchronization Channel
SCTP	Stream Control Transmission Protocol
SDMA	Space (or Spatial) Division Multiple Access
SDF	Service Data Flows
SDU	Service Data Unit
SG	Signaling Gateway
SI	System Information
SI-1	System Information message 1
SIB	System Information Block
SIMO	Single Input Multiple Output
SIP	Session Initiation Protocol
SIR	Signal-to-Interference Ratio
SMS	Short Message Service
SN	Service Node
SNR	Signal-to-Noise Ratio
SOFDMA	Scalable Orthogonal Frequency Division Multiplexing Access
SRNC	Serving Radio Network Controller
STC	Space Time Coding
TA	Tracking Area
TAI	Tracking Area Identifier
TDD	Time Division Duplex
TEID	Tunnel Endpoint Identifier
TFT	Traffic Flow Template
TM	Transparent Mode
TTI	Transmission Time Interval
UCI	Uplink Control Information
UDP	User Datagram Protocol
UE	User Equipment
UL	Uplink
UL-SCH	Uplink Shared Channel
UM	Unacknowledged Mode
UMA	Unlicensed Mobile Access
UMTS	Universal Mobile Telecommunications System
UpPTS	Uplink Pilot Time Slot
UpTS	Uplink Time Slot
VoIP	Voice over Internet Protocol
VPLMN	Visited PLMN
VRB	Virtual Resource Blocks
WCDMA	Wideband Code Division Multiple Access
Wi-Fi	Wireless Fidelity
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Networks

Chapter – 1

Long Term Evolution (LTE)

1.1

What is LTE?



- **LTE**, short for **Long Term Evolution**, is considered by many to be the obvious successor to the current generation of **UMTS 3G technology**, which is based upon **WCDMA**, **HSDPA**, **HSUPA**, and **HSPA**.

- **LTE** is not a replacement for **UMTS** (in the way that **UMTS** was a replacement for **GSM**), but rather an update to the **UMTS** technology that will enable it to provide significantly faster data rates for both uploading and downloading.

- Because **LTE** offers significant improvements over older cellular communication standards, some refer to it as a ***4G*** (**fourth generation**) technology along with **WiMax**.

- **LTE** is a standard for wireless communication of high-speed data for mobile phones and data terminals.

- It is based on the **GSM**/**EDGE** and **UMTS**/**HSPA** network technologies, increasing the capacity and speed using a different radio interface together with core network improvements. The standard is developed by the **3GPP (3rd Generation Partnership Project)**.

- Although marketed as a **4G wireless service**, **LTE** (as specified in the **3GPP** Release 8 and 9 document series) does not satisfy the technical requirements the **3GPP** consortium has adopted for its new standard generation.

- However, due to marketing pressures and the significant advancements that **WIMAX**, **HSPA**+ and **LTE** bring to the original **3G** technologies, **ITU** later decided that **LTE** together with the aforementioned technologies can be called **4G technologies**.

1.2

Specifications of LTE

- The goal of **LTE** was to increase the capacity and speed of wireless data networks using new DSP (Digital Signal Processing) techniques and modulations that were developed around the turn of the millennium.

- A further goal was the redesign and simplification of the network architecture to an **IP-based** system with significantly reduced transfer latency compared to the **3G architecture**.

- The **LTE** wireless interface is incompatible with **2G** and **3G networks**, so that it must be operated on a separate wireless spectrum.

- The **LTE** specification provides **downlink peak rates of 300 Mbit/s, uplink peak rates of 75 Mbit/s** and **QoS provisions** permitting a transfer latency of **less than 5 ms** in the **Radio Access Network (RAN)**.

- **LTE** has the ability to manage fast-moving mobiles and supports multi-cast and broadcast streams.

- LTE supports scalable carrier bandwidths, from **1.4 MHz to 20 MHz** and supports both **Frequency Division Duplexing (FDD)** and **Time-Division Duplexing (TDD)**.

- The **IP-based** network architecture, called the **Evolved Packet Core (EPC)** and designed to replace the **GPRS Core Network**, supports seamless handovers for both voice and data to cell towers with older network technology such as **GSM, UMTS** and **CDMA2000**.

- The simpler architecture results in lower operating costs (for example, each **E-UTRAN** cell will support up to four times the data and voice capacity supported by **HSPA**).

- Among other specifications, increased spectrum flexibility: 1.4 MHz, 3 MHz, 5 MHz, 10 MHz, 15 MHz and 20 MHz wide cells are standardized.

- Support for cell sizes from **tens of metres** radii (**Femto**- and **Picocells**) up to **100 km** (**62 miles**) radius **Macrocells**.

- In the lower frequency bands to be used in rural areas, **5 km (3.1 miles)** is the optimal cell size, **30 km (19 miles)** having reasonable performance, and up to **100 km** cell sizes supported with acceptable performance.

- In city and urban areas, higher frequency bands (such as **2.6 GHz** in **EU**) are used to support high speed mobile broadband; in this case, cell sizes may be **1 km (0.62 miles)** or even less.

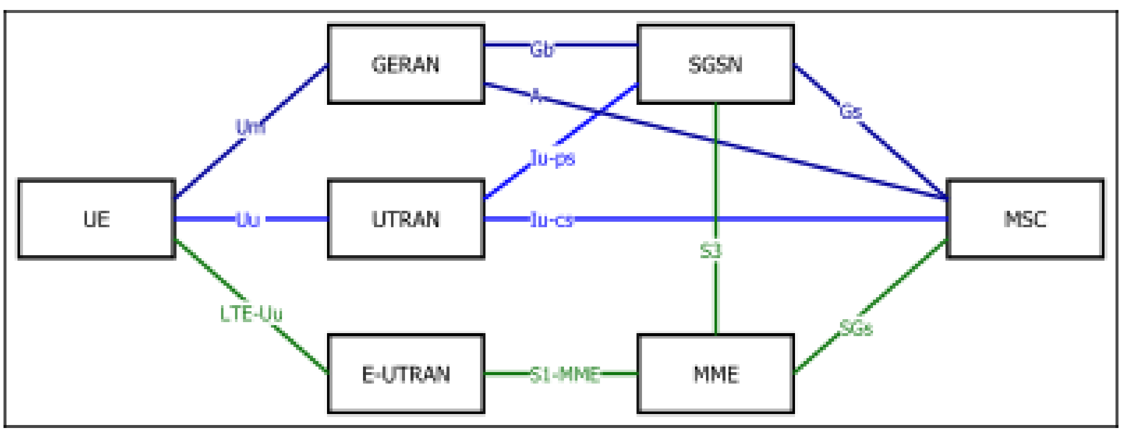


Figure: CS DOMLTE CSFB TO GSM/UMTS NETWORK INTERCONNECTS

- With its architecture based on **Internet Protocol (IP)** unlike many other **Cellular Internet Protocols**, **Long Term Evolution (LTE)** supports browsing **Web-sites**, **VoIP** and other **IP-based** services well.

- **LTE** can theoretically support downloads at **300 Megabits per second (Mbps)** or more based on experimental trials.

- However, the actual network bandwidth available to an individual **LTE** subscriber sharing the service provider's network with other customers is significantly less.

- **Long Term Evolution** service is only available in limited geographic areas, but telecommunications providers have been actively expanding their **LTE** services.

1.3 Objective of LTE

- The overall objective for **LTE** is to provide an extremely high performance **Radio-Access Technology** that offers full vehicular speed mobility and that can readily coexist with **HSPA** and earlier networks.

- Because of scalable bandwidth, operators will be able to easily migrate their networks and users from **HSPA** to **LTE** over time.

- **LTE** assumes a full **Internet Protocol (IP)** network architecture and is designed to support voice in the packet domain.

- It incorporates top-of-the-line radio techniques to achieve performance levels beyond what will be practical with **CDMA** approaches, particularly in larger channel bandwidths.

- However, in the same way that **3G** coexists with **Second Generation (2G)** systems in integrated networks, **LTE** systems will coexist with **3G** and **2G** systems.

- Multimode devices will function across **LTE/3G** or even **LTE/3G/2G**, depending on market circumstances.

- LTE capabilities include:

  → Downlink peak data rates up to 326 Mbps with 20 MHz bandwidth.

  → Uplink peak data rates up to 86.4 Mbps with 20 MHz bandwidth.

  → Operation in both TDD and FDD modes.

  → Scalable bandwidth up to 20 MHz, covering 1.4 MHz, 3 MHz, 5 MHz, 10 MHz, 15 MHz, and 20 MHz in the study phase.

→ Increased spectral efficiency over Release 6 HSPA by two to four times.

→ Reduced latency, up to 10 milliseconds (ms) round-trip times between user equipment and the base station, and to less than 100 ms transition times from inactive to active.

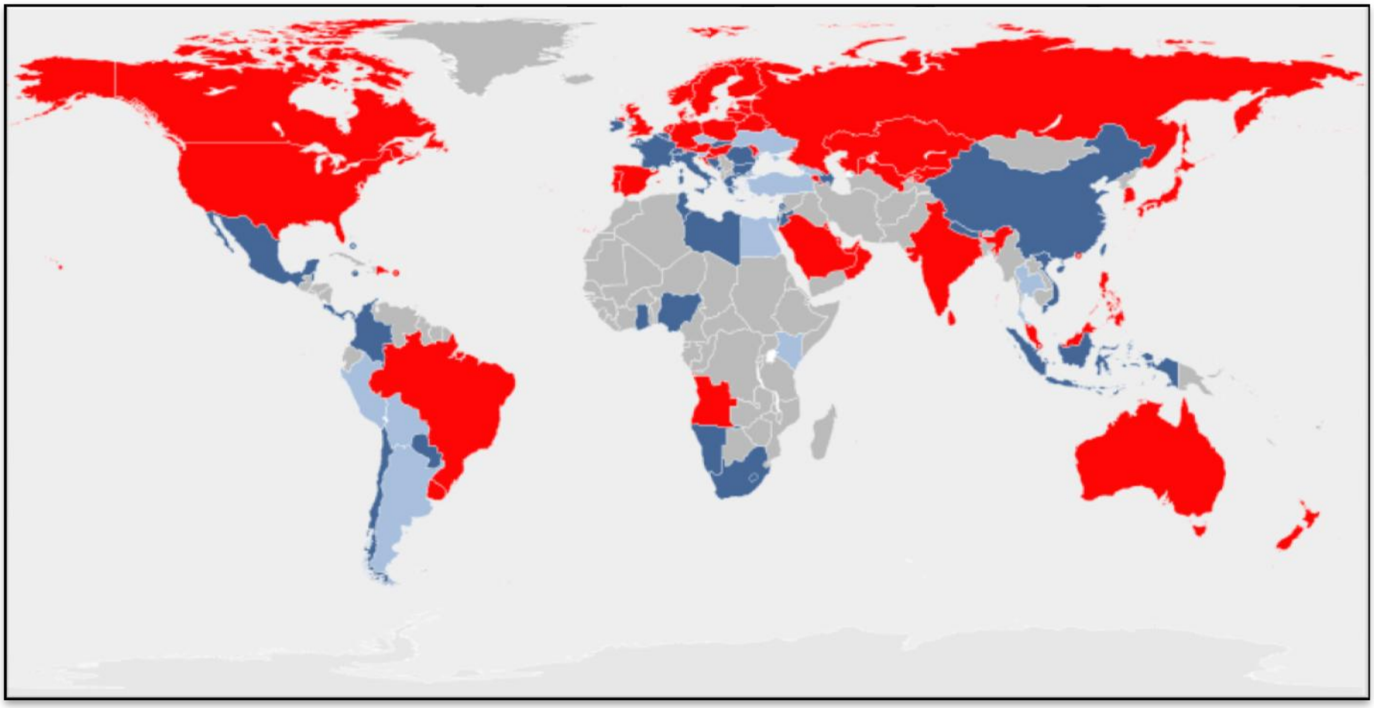


Figure: Adoption of LTE technology as of June 26, 2013.

Countries with commercial LTE service
Countries with commercial LTE network deployment on-going or planned
Countries with LTE trial systems (pre-commitment)

Chapter – 2

Small Cells In Long Term Evolution (LTE)

2.1

What is Small Cell?

- In laymen's term, a small cell solution is defined as a base station plus antenna with lower output power, smaller form factor and lower weight compared to a macro cell.

- Technically, we can define **Small Cells** as low-powered Radio Access Nodes that operate in spectrums having a range of **10 meters** to **1** or **2 kilometers**, compared to a mobile macrocell (which might have a range of a few tens of kilometers).

- Small cells are a vital element to **3G** data off-loading, and many mobile network operators see small cells as vital to managing **LTE Advanced** spectrum more efficiently compared to using just macrocells.

- It is often estimated that by **2017** a total of **5 million** Small Cells will ship annually.

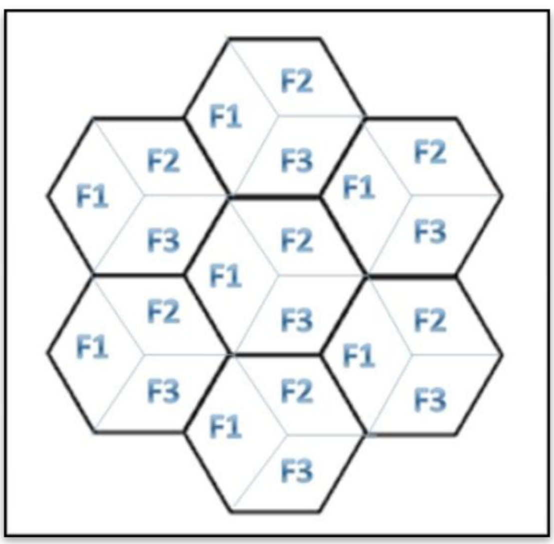


Figure: Small Cells With Cluster Size Seven (7).

2.2

Small Cell Types

- Small Cells can be of 3 types:
  1. Femtocells
  2. Picocells
  3. Microcells

- Small-Cell networks can also be realized by means of distributed radio technology consisting of centralised baseband units and remote radio heads.

- **Beam-Forming Technology** (focusing a radio signal on a very specific area) can be utilized to further enhance or focus small cell coverage.

- A common factor in all these approaches to small cells is that they are centrally managed by mobile network operators.

- Small cells provide a small radio footprint, which can range from 10 meters within urban and in-building locations to 2 km for a rural location.

- Picocells and microcells can also have a range of a few hundred meters to a few kilometers, but they differ from femtocells in that they do not always have self-organising and self-management capabilities.

2.3

Why Small Cells Are Used?

- The main purpose of small cells are:
  1. To improve mobile data coverage.
  2. To improve capacity in areas where macro cells are over-burdened.

- Small cells are used to provide in-building and outdoor wireless service.

- This means, mobile operators use small cells to extend their service coverage and/or increase network capacity and can offload traffic as much as 80% during peak times.

- It is often estimated that by 2015, 48% of mobile data traffic will be offloaded from the macro network.

  - No individual technology will dominate offloading.

- It is also believed that small cells help service providers discover new revenue opportunities through their location and presence information.

- The service provider, with the user's permission, could share this location information to update user's social media status, for instance.

- Rural coverage is also a key market that has developed as mobile operators have started to install public access **Metrocells** in remote and rural areas that either have only 2G coverage or no coverage at all.

- The cost advantages of small cells compared with macro cells make it economically feasible to provide coverage of much smaller communities - from a few tens to a few hundreds.

- To summarise, small cells are used because:

  → High-rise buildings and street canyons often cause coverage holes in certain parts of the topology.
  → High user densities also cause the capacity of macro cells to be exhausted.
  → Therefore, placing small cells at strategic points in these areas helps to overcome coverage and capacity problems.
  → Small cells are also often seen as a low-cost alternative to macro cells in rural and hard-to-reach areas because of their ease of installation.

2.4

How are Small Cells Deployed?

- Building on the global expertise in the field of small cell technology, LTE small cell technology has been developed.

- LTE small cell solution is designed to provide operators' networks with enhanced indoor and outdoor LTE coverage.

- It represents an efficient way to add capacity in areas that experience dense network traffic, increasing connectivity at a fraction of the cost of adding an entire base station.

- Commercially ready and deploying worldwide, LTE small cells are designed to bring a cost-effective way to deliver high-data throughputs to mobile subscribers.

(a)

(b)

Figure: (a) Small Cells in a populated urban location shown by the yellow highlights.
(b) Macrocells (red highlights) supporting the small cells.

2.5

Drawbacks of Small Cells

- The main drawbacks of Small Cells are as follows:

  → Radio Planning is Difficult.
  → Optimization is Complicated.
  → Higher CAPEX (capital expenditure) due to high eNB (eNodeB) cost and due to backhaul.

Chapter – 3

Small Cells Backhaul

3.1 What is Backhaul?

- In laymen's terminology, backhaul can be explained as follows:

  "Visualizing the entire hierarchical network as a human skeleton, the core network would represent the spine, the backhaul links would be the limbs, the edge networks would be the hands and feet, and the individual links within those edge networks would be the fingers and toes."

- Backhaul in telecommunication is concerned with transporting traffic between distributed sites and more centralised points of presence (POPs).

3.2 Function of Backhaul

- The main function of backhaul is:

  "To provide connectivity between large number of small cell sites back to PoP with connectivity to the core network."

3.3 Summary of Backhaul Requirements

Cost	Cheaper	→ Cost per link should be lower. → Cost per bit may be similar.
Capacity	Traffic load is lighter but burstier	Small cells generate less backhaul traffic than macrocells, but the traffic is much burstier.
Size & Weight	Smaller and lighter stations	→ Small cells require deployment in locations with limited space availability. → Therefore, compact backhauling solution is essential.
Access to Backhaul	More difficult	→ Small cells are close to users – on the street and indoors, relatively far from backhaul sites. → These sites are harder to reach than tower-based macrocells.
Installation and Commissioning	Faster, simpler, cheaper	→ Consumer femtocells are plug-and-play. → Femtocell backhauling should also work this way.

3.4 Fundamental Requirements of Backhaul Connectivity

- **Coverage**: Backhaul solution must be able to reach the small cells in difficult locations.

- **Capacity**: Backhauling ten small cells require a system with significantly greater capacity than each small cell.

- **Cost**: Small cell backhaul needs to have many more connections than a macrocell network. Cost per connection needs to be lower.

Figure: Small Cell Backhaul Unit – Convenient and Easy To Deploy.

3.5 Types of Backhaul Solutions

1. **Non-Line of Sight (NLoS) wireless: (Good for coverage, but capacity limited by available spectrum)**

   - **NLoS** wireless backhaul would be the perfect solution were it not for the small cells and **Wi-Fi** hotspots already using the entire low frequency spectrum available.
   - **NLoS** propagation requires low carrier frequencies of less than a **few GHz** which are highly prized for mobile access itself.
   - The height of the bar indicates the **MHz** of bandwidth for **uplink** and **downlink** traffic.
   - As a general rule, the bandwidth available for backhaul needs to be at least as much as that for access.
   - Some claim that the spectral efficiency of the backhaul will be higher to compensate, but this seems unlikely given that access and backhaul are operating in very similar (**NLoS**) propagation conditions and with interference from nearby co-channel transmitters.

2. **Microwave: (Plenty of spectrum, a mature technology for fixed links)**

   - Large amounts of bandwidth are available at ‘microwave’17 frequencies from 10-60GHz, which in turn means lots of capacity.
   - These frequencies are already widely used for high-capacity fixed communication links with Point-to-Point and multipoint topologies.
   - The small wavelength at these frequencies brings a mix of benefits and challenges.

- On the plus side, high-gain, compact antennas are easy to build which improves link budgets, however such antennas need to be carefully aligned to the other end of the link.
- The short wavelength also means that effectively line of sight is the only option as diffraction and penetration around or through buildings and trees incurs high losses.
- This can be turned to an advantage as the high attenuation helps reduce interference from nearby links wishing to re-use the same frequencies.
- Given the maturity of technologies and availability of spectrum for high-capacity backhaul, microwave looks to be the mainstay of small cell backhaul solutions.

3. **NLoS backhaul is built into the LTE standards:**

- A feature rather like NLoS backhaul, called ‘in-band relay’, is included in the LTE advanced standard16 where a base station can use half of the access spectrum to backhaul signals to a connected ‘donor’ cell site.
- Whilst this is good for extending coverage for early deployments, spectral efficiency for end-user traffic is effectively halved, so it is not a capacity-enhancing solution needed to meet increasing demand.

4. **Point-to-Point uses one or more links to connect cells to a PoP:**

- Each link requires an antenna and radio at each end, and so the PoP site can easily become crowded with too many antennas.
- The solution to this is to create a tree structure of intermediate nodes.
- Provisioning capacity across the tree requires consideration of the number of downstream small cells, so adding in new small cells may require a re-planning of the network.
- Furthermore, since frequency allocations are often managed on a per link basis, building out such networks can be time consuming.

- This has not prevented widespread use ofmicrowave Point-to-Point for macrocell sites, but for the rapid rollout and continuous evolution required for small cell networks, it is likely to be untenable.

5. **<u>Multipoint topology is what has always been used in the access network itself:</u>**

- A central ‘hub’ shares its capacity amongst a number of terminals.
- Since traffic demands are bursty, it is not sensible to permanently allocate a fixed resource to each small cell that may only need it occasionally.
- It is more efficient to pool resources across a larger number of cell sites and average out any difference in traffic demand at different times of day.
- The result is a much higher utilisation of the spectral resource, and ultimately more useable capacity per Hz of spectrum.
- It is not only the capacity that is shared, but the equipment too.
- Like access networks, hub sites use sector antennas which provide coverage over a large surrounding area, each serving many small cells.
- This has the added benefit of halving installation costs, since only the small cell end of the link needs to be visited to connect up the backhaul to the hub.
- Multipoint microwave is fundamentally well suited to small cell backhaul due to:

  → High-capacity

  → Wide bandwidths are available at microwave frequencies, and capacity is pooled between a large number of bursty small cells

  → Rapid rollout

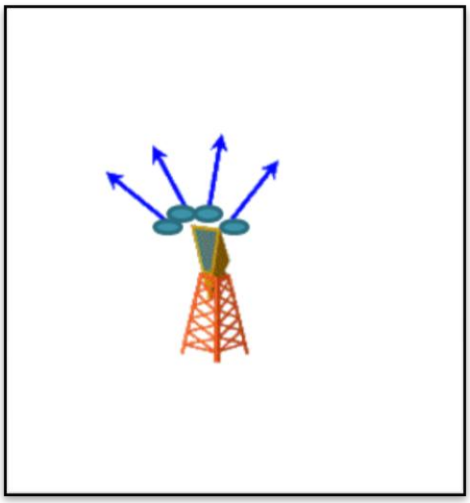
  → Multipoint spectrum is normally area licensed so does not require regulator frequency assignment for every new link

  → New small cell sites can be added without a visit to the hub site

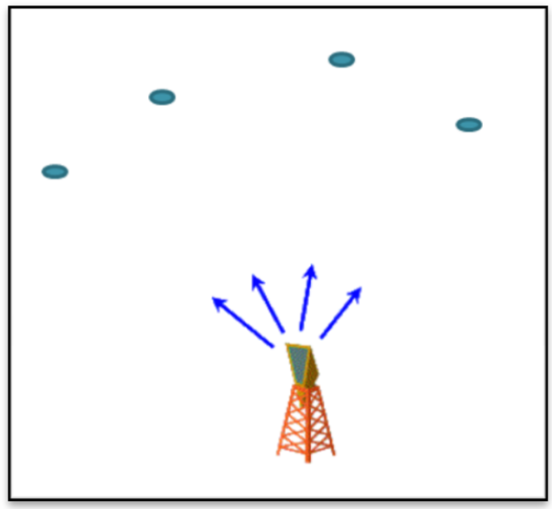
  → Low-cost

→ Multipoint topology improves spectral utilisation, reducing bandwidth needed for a given number of small cells at a given level of performance

→ Shared antennas and radios at the hub site means costs can be amortised over the many small cells supported.



(a)



(b)

Figure: (a) & (b) demonstrates point to multipoint backhaul

6. <u>Line Of Sight (LoS) Coverage In Urban Environments:</u>

- As with all microwave based solutions, LoS is required for links to function with the desired quality of service.
- The likelihood of line-of-sight (LoS) is an essential component in any radio channel model.
- It is particularly useful for radio network planning and urban coverage prediction.
- Empirical LoS models are hard to derive due to a strong dependency on local topology and the need for large measurement datasets.

- Since buildings are the major obstructions in a dense urban environment, we propose a new theoretical model to determine the LoS probability for air-to-ground channels based on local building geometry and knife-edge diffraction theory.
- The model takes into account key statistical parameters such as building height, building size, building coverage, street width and street angle distribution.
- The theoretical model is shown to agree well with ray tracing simulation results.
- The statistical parameters, such as mean building height, percentage of area covered by buildings (building coverage) and building density, can all be easily obtained for a specific location.
- We also derive equations for the likelihood of LoS for a direct slant path.
- These equations can be used in the analysis of air-to-ground channels.

7. Multiple backhaul solutions:

1. Fibre where practical and cost-effective.
2. High-capacity multipoint microwave wireless everywhere else using an effective selection process for the best suited solution at each small cell deployment.

3.6

Small Cell Backhaul Designing

- Backhaul provides for transmission link or connectivity between a cell site and the core network.

- In our case we have used the point to multipoint microwave backhaul which is suitable as discussed earlier.

3.6.1 Designing Backhaul with Frequency Reuse

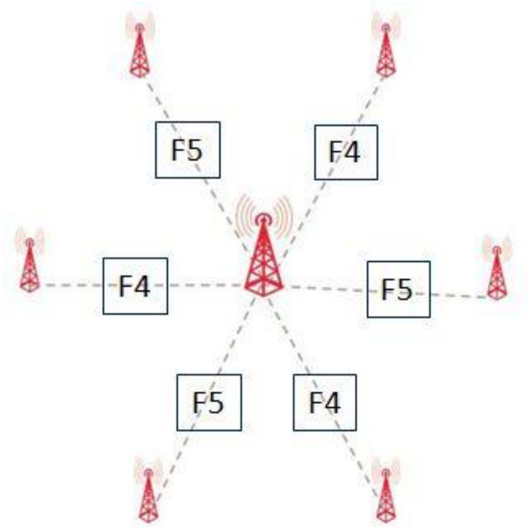


Figure: Small Cell Backhaul Layout.

- The allocated frequency for our backhaul is **10MHz**, which is divided into two parts of **5MHz** each (**F4** = **F5** = **5MHz**).
- The implementation of frequency reuse is shown in above Figure; the adjacent **eNBs** uses different frequencies to avoid Interference among them.

- Overbooking factor depends on the percentage of subscribers who are on at the peak time and the percentage downloading on the internet at the same time.
- We are assuming an overbooking factor of 1.6.
- Therefore the required backhaul spectrum = 1.6 × 27.5 = 44 **Mb/s**.

3.6.2 Backhaul Simulation

- Motorola P2P Link Planner was used to simulate the backhaul for Small Cells. The layout of the design is shown below:

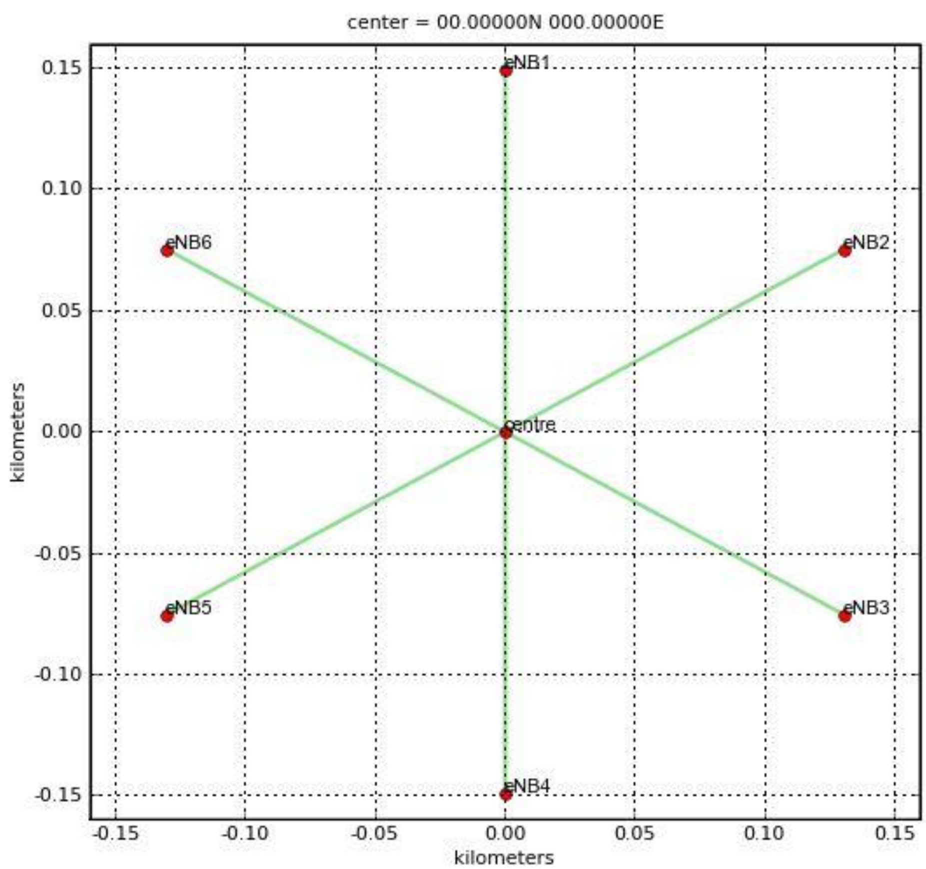


Figure: Small Cell Backhaul Layout

- The central eNB provides the backhaul for the surrounding six eNBs of smaller size.
- A hexagonal shape is formed similar to the ones used in Vienna Simulator.
- **Input Parameters:**
  - Inter eNB distance: 150m
  - Transmitting BW: 5MHz
  - Antenna type: Motorola Integrated Dual Polar Antenna for center, Dual Polar Parabolic SPD1 2.3 for others.
  - Height: 20m for center node, 15m for others
  - Gain: 18dBi for center, 13.8 dBi for others

3.6.3 Simulation Results

- We are looking for the maximum throughput that can be provided by our backhaul with the available resources.
- From table 3.1 we can see that the aggregate throughput value is 48.4 Mb/s. The table shows:
  I. the inter eNB distances (km)
  II. the height of the eNBs(m)
  III. the antenna gain (dBi) and
  IV. the power loss (dB)

Links

Name	Range (km)	Product	Aggregate Throughput (Mbps)	Link Availability	Left Height (m)	Left Gain (dBi)	Right Height (m)	Right Gain (dBi)	Link Loss (dB)
centre to eNB1	0.149	PTP25600	48.4	100.0000	20	18.0	15	13.8	84.0
centre to eNB2	0.150	PTP48600	48.4	100.0000	20	22.0	15	22.0	89.9
centre to eNB3	0.150	PTP25600	48.4	100.0000	20	18.0	15	18.0	84.1
centre to eNB4	0.149	PTP49600	48.4	100.0000	20	22.0	15	22.0	89.8
centre to eNB5	0.150	PTP25600	48.4	100.0000	20	18.0	15	18.0	84.1
centre to eNB6	0.150	PTP49600	48.4	100.0000	20	22.0	15	22.0	89.9

Table: 3.1

3.6.4 Overview of the link between two eNBs

- Considering the link between the centre and one of the surrounding eNBs, we can compare the configurations illustrated in the Table 3.2.
- The EIRP is calculated from the formula given below using the values stated in the table.
- The total path loss is the summation of all the other losses in the link.
- In radio communication systems, effective **Isotropically** radiated power (**EIRP**) is the amount of power that a theoretical isotropic antenna (which evenly distributes power in all directions) would emit to produce the peak power density observed in the direction of maximum antenna gain.
- **EIRP** can take into account the losses in transmission line and connectors and includes the gain of the antenna.
- The **EIRP** is often stated in terms of decibels over a reference power emitted by an isotropic radiator with equivalent signal strength.
- The **EIRP** allows comparisons between different emitters regardless of type, size or form.
- From the **EIRP**, and with knowledge of a real antenna's gain, it is possible to calculate real power and field strength values.

$$EIRP = P_T - L_c + G_a$$

Where $EIRP$ and P_T (output power of transmitter) are in **dBm**, cable losses (L_c) are in **dB**, and antenna gain (G_a) is expressed in **dBi**, relative to a (theoretical) isotropic reference antenna.

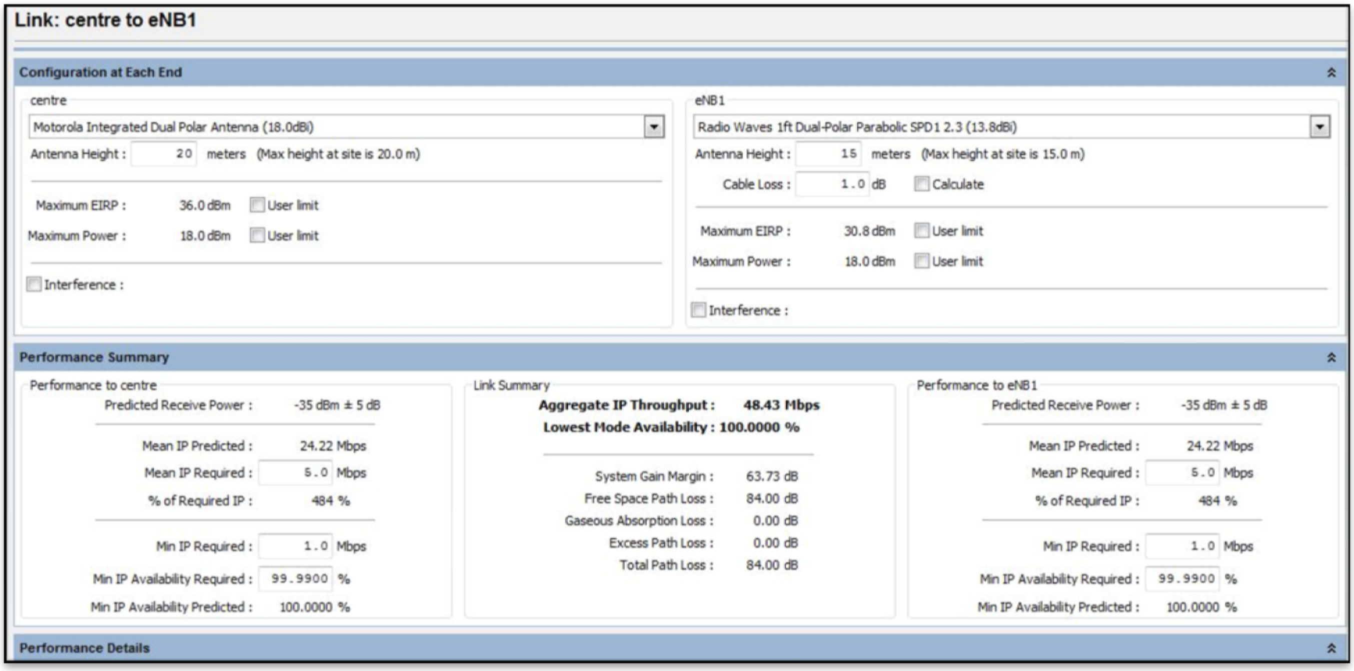


Table: 3.2

3.6.5 Line of Sight (LOS) Link

- The Line of Sight communication needs to ensure that there are no obstacles between any two links, thus a direct link is established between the transmitter and the receiver which means it lies in the first Fresnel zone.
- Table 3.3 demonstrates the LOS link between the centre and the eNB1.
- The elliptical shape is referring to the radiation path between the two links.

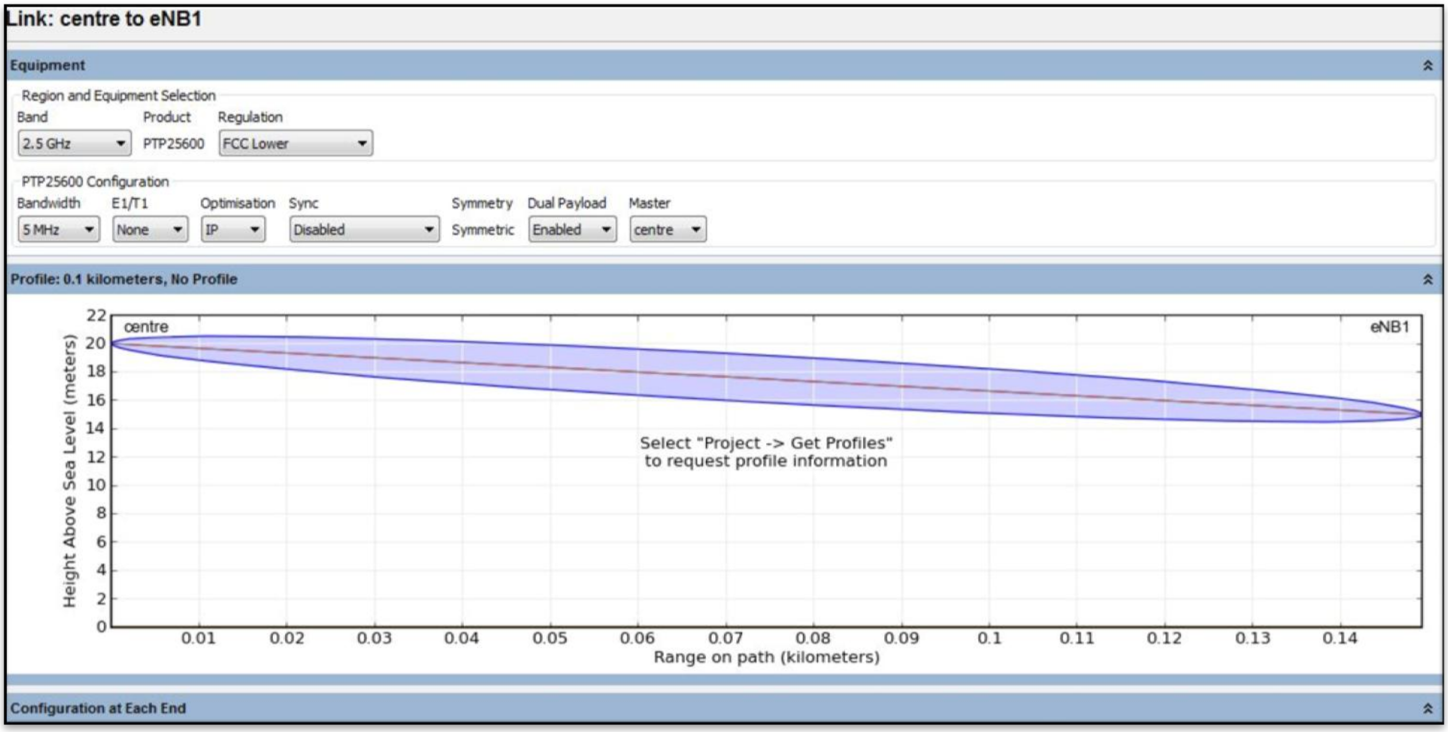

Link: centre to eNB1
Equipment
Region and Equipment Selection
Band
Product
Regulation
2.5 GHz
PTP25600
FCC Lower
PTP25600 Configuration
Bandwidth
E1/T1
Optimisation
Sync
Symmetry
Dual Payload
Master
5 MHz
None
IP
Disabled
Symmetric
Enabled
centre
Profile: 0.1 kilometers, No Profile
centre
eNB1
Select "Project -> Get Profiles"
to request profile information
Height Above Sea Level (meters)
Range on path (kilometers)
Configuration at Each End

Table: 3.3

3.6.6 Bill of Materials

The backhaul set-up requires the equipments listed in Table 3.4 below.

Bill of Materials for try3

P/N	Description	Qty
(no part number)	Radio Waves 1ft Dual-Polar Parabolic SPD1 2.3	1
WB2782	PTP 25600 (5 MHz) Integrated - Link Complete	2
WB2784	PTP 25600 (5 MHz) Integrated - End Complete	1
WB2785	PTP 25600 (5 MHz) Connectorised - End Complete	1
WB2907	LPU End Kit PTP 600 (2 kits required per Link)	12
WB3176	328 ft (100 m) Reel Outdoor Copper Clad CAT5E (Recommended for PTP)	6
WB3225	PTP 49600 (5 MHz) Integrated - Link Complete	2
WB3378	PTP 48600 Full Integrated - Link Complete	1

Table 3.4

Chapter – 4

Femtocells in LTE

4.1

What are Femtocells?

- **Femtocells** can be defined as:

> *"Low-power access points using mature mobile technology in licensed spectrum generating coverage and capacity over internet-grade backhaul at low prices with full operator management self-organising, self-managing."*

- In telecommunications, a **Femtocell** is a small, low-power cellular base station, typically designed for use in a home or small business.

- A broader term which is more widespread in the industry is small cell, with **Femtocell** as a subset.

- It connects to the service provider's network via broadband (such as DSL or cable); current designs typically support two to four active mobile phones in a residential setting, and eight to 16 active mobile phones in enterprise settings.

- A **Femtocell** allows service providers to extend service coverage indoors or at the cell edge, especially where access would otherwise be limited or unavailable.

- Although much attention is focused on **WCDMA**, the concept is applicable to all standards, including **GSM**, **CDMA2000**, **TD-SCDMA**, **WiMAX** and **LTE** solutions.

- For a mobile operator, the attractions of a **Femtocell** are improvements to both coverage and capacity, especially indoors.

- Consumers benefit from improved coverage and potentially better voice quality and battery life.

- Depending on the carrier they may also be offered more attractive tariffs, e.g., discounted calls from home.

- **Femtocells** are an alternative way to deliver the benefits of **Fixed-Mobile Convergence** **(FMC)**.

- The distinction is that most **FMC** architectures require a new (dual-mode) handset which works with existing unlicensed spectrum home/enterprise wireless access points, while a **Femtocell** based deployment will work with existing handsets but requires installation of a new access point that uses licensed spectrum.

- In **3GPP** terminology, a **Home Node B** **(HNB)** is a **3G Femtocell**. A **Home eNode B (HeNB)** is an **LTE** **Femtocell**.

- Typically the range of a standard base station may be up to **35 kilometres (22 mi)**, a **Microcell** is less than two kilometers wide, a **Picocell** is 200 meters or less, and a **Femtocell** is on the order of 10 meters.

4.2

Femtocell Architecture

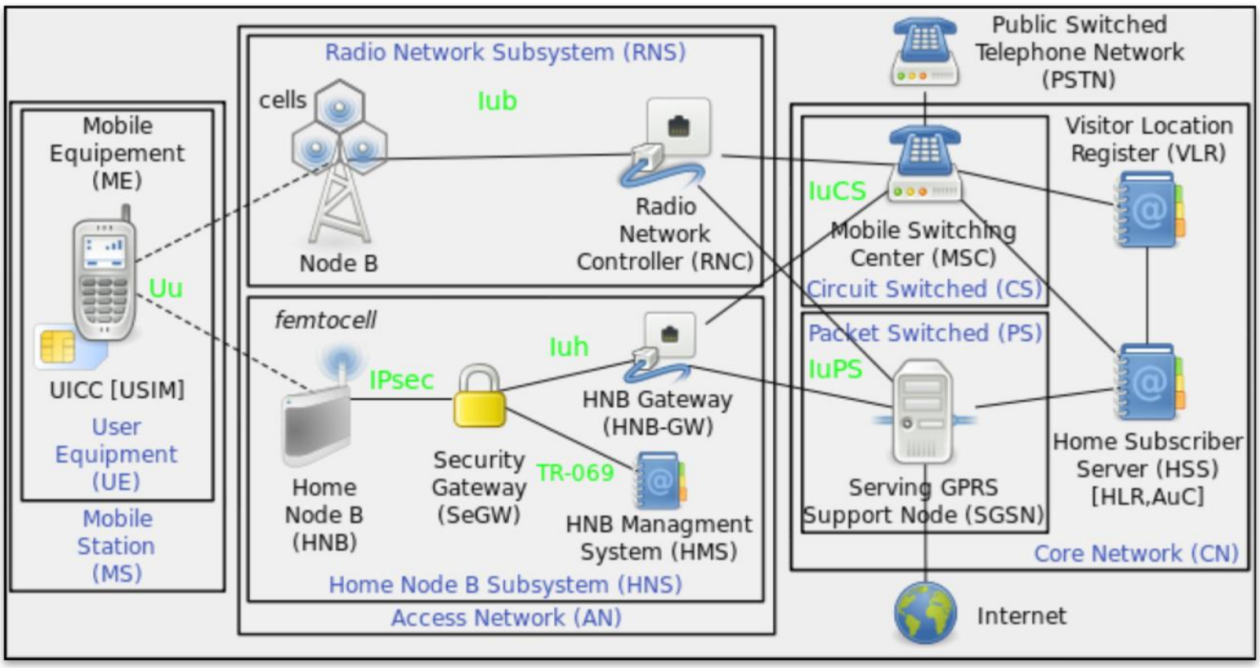


Figure: **Simplified version of traditional Node B and Home Node B (3G femtocell) in 3G architecture.**

- **Femto/ HeNB** fits well with flat Enhanced Packet Core architecture.
- **HeNB** Gateway is optional and transparent, delivering concentration and scalability without sacrificing architectural simplicity.
- Reuses standardized open management approach.
- **Femtocells** form an essential element in the heterogeneous network toolkit for **LTE** operators (no more one-size-fits-all approach).

4.3

Operating Mode of Femtocells

- **Femtocells** are sold by a Mobile Network Operator (MNO) to its residential or enterprise customers.
- A **Femtocell** is typically the size of a residential gateway or smaller, and connects to the user's broadband line.
- Integrated **Femtocells** (which include both a DSL router and femtocell) also exist.
- Once plugged in, the **Femtocell** connects to the MNO's mobile network, and provides extra coverage.
- From a user's perspective, it is plug and play, there is no specific installation or technical knowledge required—anyone can install a **Femtocell** at home.
- In most cases, the user must then declare which mobile phone numbers are allowed to connect to his **Femtocell**, usually via a web interface provided by the MNO.
- This needs to be done only once.
- When these mobile phones arrive under coverage of the **Femtocell**, they switch over from the Macrocell (outdoor) to the **Femtocell** automatically.
- Most **MNOs** provide a way for the user to know this has happened, for example by having a different network name appear on the mobile phone.
- All communications will then automatically go through the **Femtocell**.

- When the user leaves the **Femtocell** coverage (whether in a call or not) area, his phone hands over seamlessly to the macro network.

- **Femtocells** require specific hardware, so existing **WiFi** or **DSL** routers cannot be upgraded to a **Femtocell**.

- Once installed in a specific location, most **Femtocells** have protection mechanisms so that a location change will be reported to the MNO.

- Whether the **MNO** allows **Femtocells** to operate in a different location depends on the **MNO's** policy.

- International location change of a **Femtocell** is not permitted because the **Femtocell** transmits licensed frequencies which belong to different network operators in different countries.

4.4

The Need For LTE Femtocells

- Applications of **Femtocells** include:
  → Residential
  → Enterprise
  → Hot spot
  → Metro

- 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.

- In their 2011 *Visual Networking Index*, Cisco projects that global mobile data traffic will increase 26-fold between 2010 and 2015. This has been called the "mobile data tsunami".

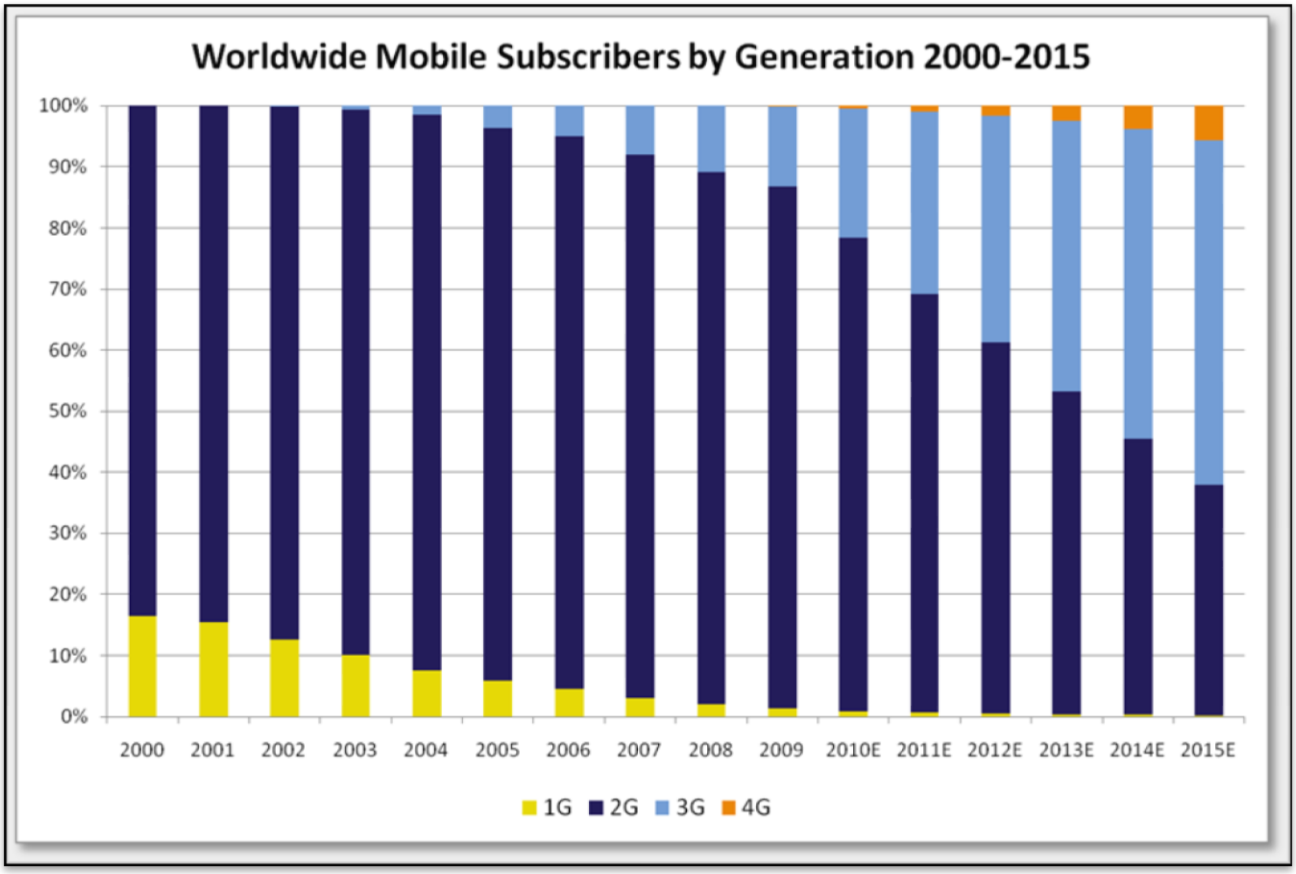
- Traditional macro cellular networks alone, even with advances in **4G** technology, simply cannot meet this demand because:

  → There is a limit to how many outdoor cell sites can be built. Cell sites are costly, and new site proposals often encounter local resistance.
  → The spectrum available to any particular operator is limited; the growth in capacity from **4G** spectral efficiency plus anticipated new spectrum will still be outstripped by increase in demand.
  → Cell site backhaul, though available, is expensive.

- As a result, macro radio access networks will not be able to keep pace with the growth in demand for mobile data.

- Meanwhile, the price that consumers will pay, on a per megabit basis, is declining. In 2007, BlackBerry dominated the smartphone market.

- Users paid $30-$45 a month and typically consumed **25 MB** of data.
- Today, an iPhone or Android user pays $30/month and often consumes over **500MB** of data.
- To handle the data tsunami cost-effectively and provide ubiquitous coverage, operators must offload data traffic from the macro-cellular network to the fixed line broadband network when users are inside buildings.
- Consumers expect this offload to be done in a transparent fashion, wherever they are—especially indoors.
- As consumers become accustomed to **LTE** speeds, they will expect these speeds whether they are outdoors or in-building.
- It is believed that **Femtocells** provide the best solution for seamless, transparent offload and ubiquitous coverage for high-speed data.
- **LTE Femtocells** need to be Multimode Leading mobile operators are planning aggressive **LTE** service roll-outs.
- However, even in the most optimistic of scenarios, **3G** subscriber devices will outnumber **LTE** devices for many years to come.
- Historically there has been a 10-year interval between the ratification of a new generation standard and the time when its device shipments overtake those of the previous generation.
- As an example, ABI Research reported that shipments of 3G handsets overtook **2G** handset shipments only in Q1 of 2010.
- The data below from Deutsche Bank suggests that this pattern will continue in the migration from **3G** to **4G**.



- Furthermore, while **LTE** standards for data are well established, there are still multiple proposed ways to deliver voice services over **LTE** networks.

- The likely outcome of this will be that operators will continue to deliver voice via their **3G** networks even as they move data to **LTE**.

- As a result, subscriber devices will be a mix of **3G-only** and **4G plus 3G**, with very few being **4G-only**.

- To support these subscribers comprehensively across all types of mobile services, operators must similarly deploy a multi-mode radio access infrastructure including multimode **Femtocells**.

	3G Femtocell	**4G Femtocell**	**Multimode**
Data on 4G/3G Device	X	XX	XX
Data on 3G-only Device	X	via macro	X
Voice	X	via macro	X

4.4 Benefits For Users

- The main benefits for an end-user are the following:

→ "5 bar" coverage when there is no existing signal or poor coverage.
→ Higher mobile data capacity, which is important if the end-user makes use of mobile data on his mobile phone (may not be relevant to a large number of subscribers who instead use WiFi where femtocell is located).
→ Depending on the pricing policy of the MNO, special tariffs at home can be applied for calls placed under **Femtocell** coverage.
→ For enterprise users, having **Femtos** instead of **DECT** ("cordless" home) phones enables them to have a single phone, so a single contact list, etc.
→ Improved battery life for mobile devices due to reduced trasmitter-receiver distance.
→ **Femtocells** can be used to give coverage in rural areas.

- Simplified version of traditional **Node B** and **Home Node B** (**3G Femtocell**) in **3G** architecture.

- The standards bodies have published formal specifications for **Femtocells** for the most popular technologies, namely **WCDMA**, **CDMA2000**, **LTE** and **WiMAX**.

- These all broadly conform to an architecture with three major elements:

1. The **Femtocell** access points themselves, which embody greater network functionality than found in **Macrocell** base-stations, such as the radio resource control functions. This allows much greater

autonomy within the **Femtocell**, enabling self-configuration and self-optimisation.

2. **Femtocells** are connected using broadband IP, such as DSL or cable modems, to the network operator's core switching centers.
3. The **Femtocell** gateway, comprising a security gateway that terminates large numbers of encrypted IP data connections from hundreds of thousands of **Femtocells**, and a signaling gateway which aggregates and validates the signaling traffic, authenticates each **Femtocell** and interfaces with the mobile network core switches using standard protocols.
4. The management and operational system which allows software updates and diagnostic checks to be administered. These typically use the same TR-069 management protocol published by the Broadband Forum and also used for administration of residential modems.

Chapter – 5

Performance Analyses of Small Cells and Femtocells in LTE

5.1 MATLAB Simulation of Small Cells

- In order to make a comparison between the Small Cells and Femtocells we used the **Vienna Simulator** in MATLAB.

5.1.1 Small Cell Radio Planning

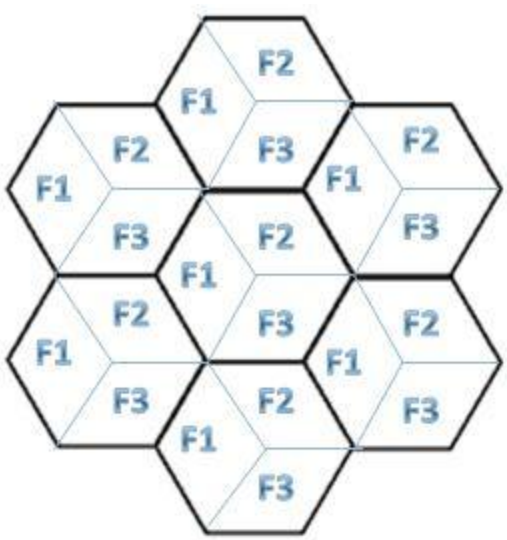


Figure: Frequency Distribution

- Licensed Frequency = 30MHz
- The frequencies of each cell = F1 = F2 = F3 = 5MHz

Overall Radio Planning:

- Frequency per eNB = 5 + 5 + 5= 15MHz
- Backhaul Spectrum with Frequency Reuse = 10MHz
- For High Mobility Users = 5MHz
- Total Spectrum = 15 + 15 = **30MHz**

5.1.2 LTE Downlink System Level Simulator (Vienna)

- **Input Parameters**:
  1. Bandwidth: 5MHz
  2. Inter eNB distance: 150 m
  3. Transmitter Power: 23 dBm
  4. Antenna Gain: 5 dBi
  5. SISO link for Antennas

- It gives various results among which the most important outputs are:
  i. Average UE Throughout (mbps)
  ii. Average UE Spectral Efficiency (bit/cu)
  iii. Number of UEs.

5.1.3 MATLAB Coding for Small Cell

```
close all force;
clc;
clear all
clear global;
clear classes;

simulation_type = 'tri_sector_tilted';

% Possible simulation types now:
%   - 'tri_sector'
%   - 'tri_sector_tilted',
'tri_sector_tilted_4x2',
'tri_sector_tilted_4x4'
%   - 'tri_sector_plus_femtocells'
%   - 'six_sector_tilted'
%   - 'capesso_pathlossmaps'
%   - 'omnidirectional_eNodeBs'

LTE_config = LTE_load_params(simulation_type);

%% If you want to modify something taking as a
base the configuration file, do it here: here
an example is show that changes the inter-
eNodeB distances based on the
LTE_load_params_hex_grid_tilted config file.

% Some changes to the base configuration, in
case you would need/want them
LTE_config.show_network                = 0;
LTE_config.nTX                         = 2;
LTE_config.nRX                         = 2;
LTE_config.tx_mode                     = 2;
LTE_config.scheduler                   = 'prop
fair Sun'; % prop fair Sun % round robin
LTE_config.shadow_fading_type          = 'none';
LTE_config.compact_results_file        = true;
```

```
LTE_config.delete_ff_trace_at_end     = true;
LTE_config.UE_cache                   = true;
LTE_config.simulation_time_tti        = 10;
LTE_config.UE_cache_file              = 'auto';
LTE_config.adaptive_RI                = 2;
LTE_config.keep_UEs_still             = true;
LTE_config.UE_per_eNodeB              = 10;
LTE_config.scheduler_params.av_window = 20;
LTE_config.map_resolution             = 10;
LTE_config.pregenerated_ff_file       = 'auto';
LTE_config.trace_version              = 'v1';
% 'v1' for pregenerated precoding. 'v2' for
run-time-applied precoding
LTE_config.inter_eNodeB_distance      = 150;
LTE_config.eNodeB_tx_power            = 40;
LTE_config.frequency                  = 900e6;
LTE_config.bandwidth                  = 5e6;
LTE_config.max_antenna_gain           = 15;
output_results_file = LTE_sim_main(LTE_config);

simulation_data     =
load(output_results_file);
GUI_handles.aggregate_results_GUI =
LTE_GUI_show_aggregate_results(simulation_data);
GUI_handles.positions_GUI =
LTE_GUI_show_UEs_and_cells(simulation_data,GUI_
handles.aggregate_results_GUI);
```

The Matlab Simulation of the Small Cell is demonstrated below:

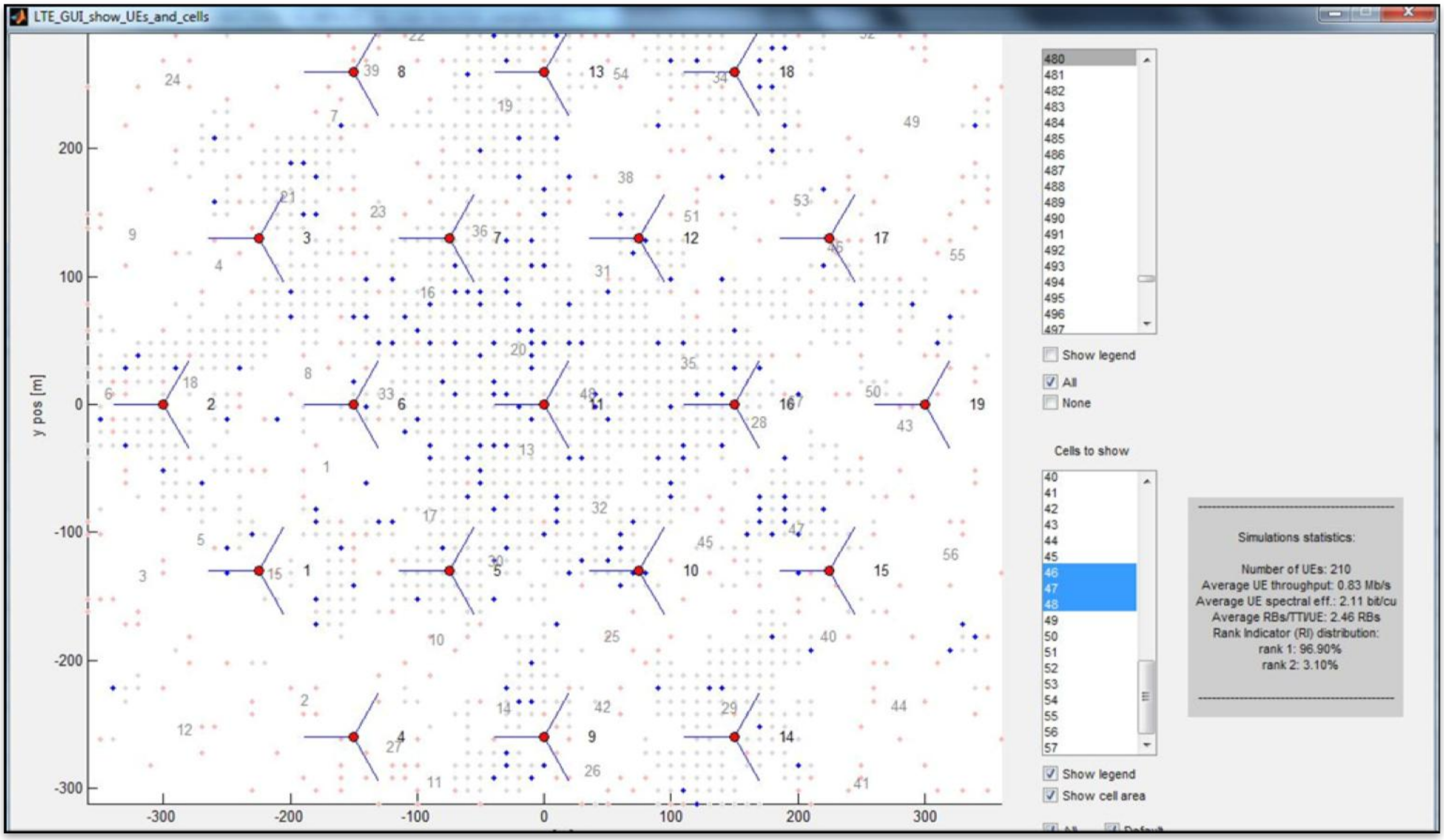


Figure: The Distribution of eNBs and UEs in a given area.

- The tri-sectored shapes with red dots are the eNBs, we can see from the figure that there are 19 eNBs.
- They are arranged in hexagonal pattern.
- There are two tiers of small cells.
- The central one is the macro cell which is providing backhaul for the two layers of small cells surrounding it.
- The blue dots are the UEs scattered throughout the ROI.

5.1.4 The average UE throughput Vs SINR is demonstrated below:

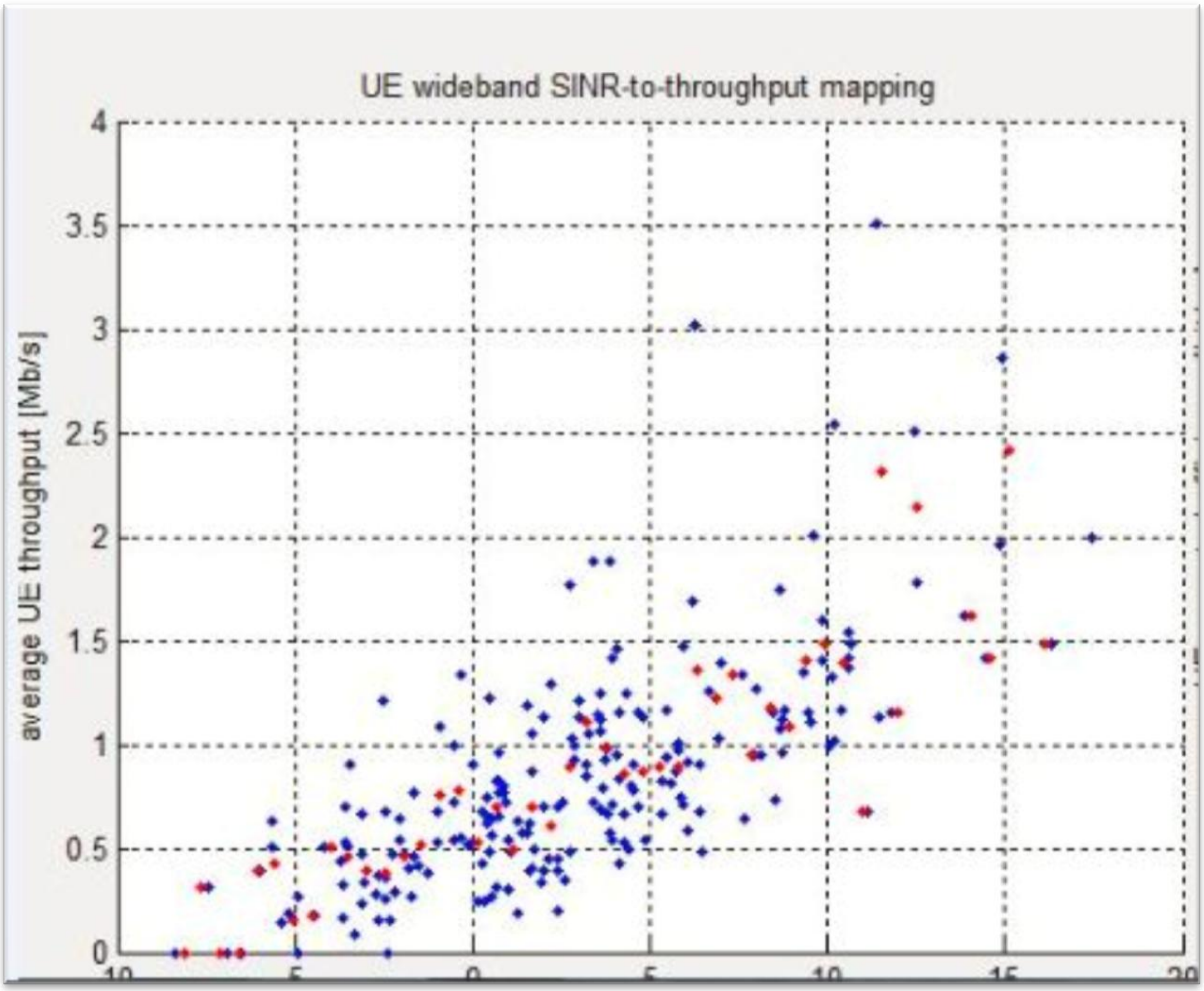


Figure: Average UE Throughput Vs SINR

- **Throughput:**

  It is the average rate of successful message delivery over a communication channel.

This data may be delivered over a physical or logical link, or pass through a certain network node.

The throughput is usually measured in bits per second (bit/s or bps), and sometimes in data packets per second or data packets per time slot.

The average UE throughput is shown by the straight line which is **0.83Mb/sec**.

5.1.5 The average UE spectral efficiency Vs SINR is shown below:

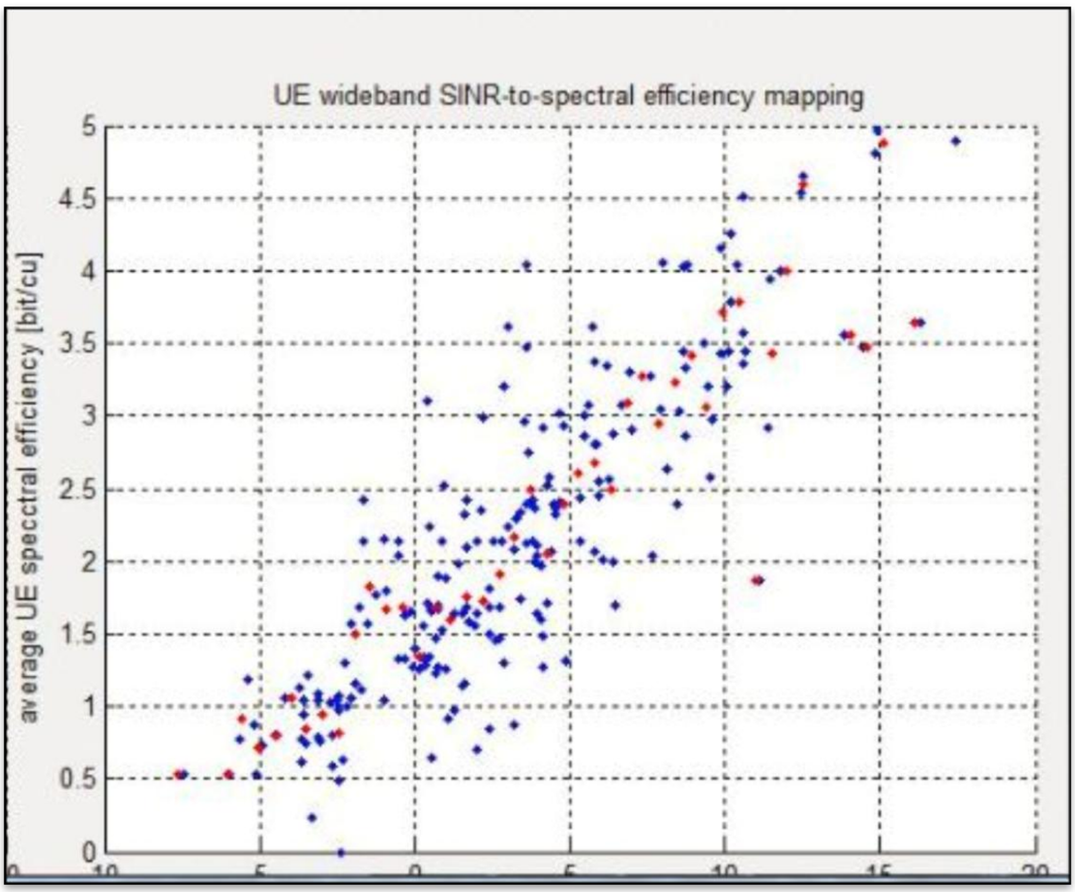


Figure: Average UE Spectral Efficiency Vs SINR

- **Spectral Efficiency**:

  Spectral efficiency refers to the information rate that can be transmitted over a given bandwidth in a specific communication system.

  It is a measure of how efficiently a limited frequency spectrum is utilized by the physical layer protocol, and sometimes by the media access control (the channel access protocol).

  The link spectral efficiency of a digital communication system is measured in (bit/s)/Hz which is equivalent to bits per channel use (bit/cu).

  The average UE spectral efficiency is **2.11 bit/cu.**

5.1.6 Throughput Calculation:

- Number of UEs = 210
- Number of eNBs = 19
- Average UE Throughput = 0.83Mb/s
- eNodeB throughput = (210*.83*3)/19 = 27.5Mbps

5.2 MATLAB Simulation of Femtocells

- A femtocell is a small wireless access point that transmits voice and data cellular signals within a home or small office.
- These are deployed in crowded urban areas where small cells alone cannot meet the demand.
- There is no planning for the backhaul of the femtocells since these are randomly distributed.

5.2.1 Femtocell Simulation in Vienna

- Input Parameters – It gives various results among which the most important outputs are:
  1. Average UE Throughout (Mbps)
  2. Average UE Spectral Efficiency (bit/cu)
  3. Number of UEs.

5.2.2 Coding for Femtocells:

```
close all force;
clc;
clear all
clear global;
clear classes;

simulation_type = 'tri_sector_plus_femtocells';

% Possible simulation types now:
%   - 'tri_sector'
%   - 'tri_sector_tilted', 'tri_sector_tilted_4x2',
'tri_sector_tilted_4x4'
%   - 'tri_sector_plus_femtocells'
%   - 'six_sector_tilted'
%   - 'capesso_pathlossmaps'
%   - 'omnidirectional_eNodeBs'

LTE_config = LTE_load_params(simulation_type);

%% If you want to modify something taking as a base
the configuration file, do it here: here an example
is show that changes the inter-eNodeB distances
based on the LTE_load_params_hex_grid_tilted config
file.

% Some changes to the base configuration, in case
you would need/want them
LTE_config.show_network                     = 0;
LTE_config.nTX                              = 2;
LTE_config.nRX                              = 2;
LTE_config.tx_mode                          = 2;
LTE_config.scheduler                        = 'prop fair
Sun'; % prop fair Sun % round robin
```

```
LTE_config.shadow_fading_type          = 'none';
LTE_config.compact_results_file        = true;
LTE_config.delete_ff_trace_at_end      = true;
LTE_config.UE_cache                    = true;
LTE_config.simulation_time_tti         = 10;
LTE_config.UE_cache_file               = 'auto';
LTE_config.adaptive_RI                 = 2;
LTE_config.keep_UEs_still              = true;
LTE_config.UE_per_eNodeB               = 10;
LTE_config.scheduler_params.av_window = 20;
LTE_config.map_resolution              = 10;
LTE_config.pregenerated_ff_file        = 'auto';
LTE_config.trace_version               = 'v1';    %
'v1' for pregenerated precoding. 'v2' for run-time-
applied precoding
LTE_config.eNodeB_tx_power             = 40;
LTE_config.frequency                   = 900e6;
LTE_config.bandwidth                   = 5e6;
LTE_config.max_antenna_gain            = 15;
output_results_file    = LTE_sim_main(LTE_config);

simulation_data        = load(output_results_file);
GUI_handles.aggregate_results_GUI =
LTE_GUI_show_aggregate_results(simulation_data);
GUI_handles.positions_GUI          =
LTE_GUI_show_UEs_and_cells(simulation_data,GUI_hand
les.aggregate_results_GUI);
```

5.2.3 The Matlab Simulation of the Femtocell is demonstrated below:

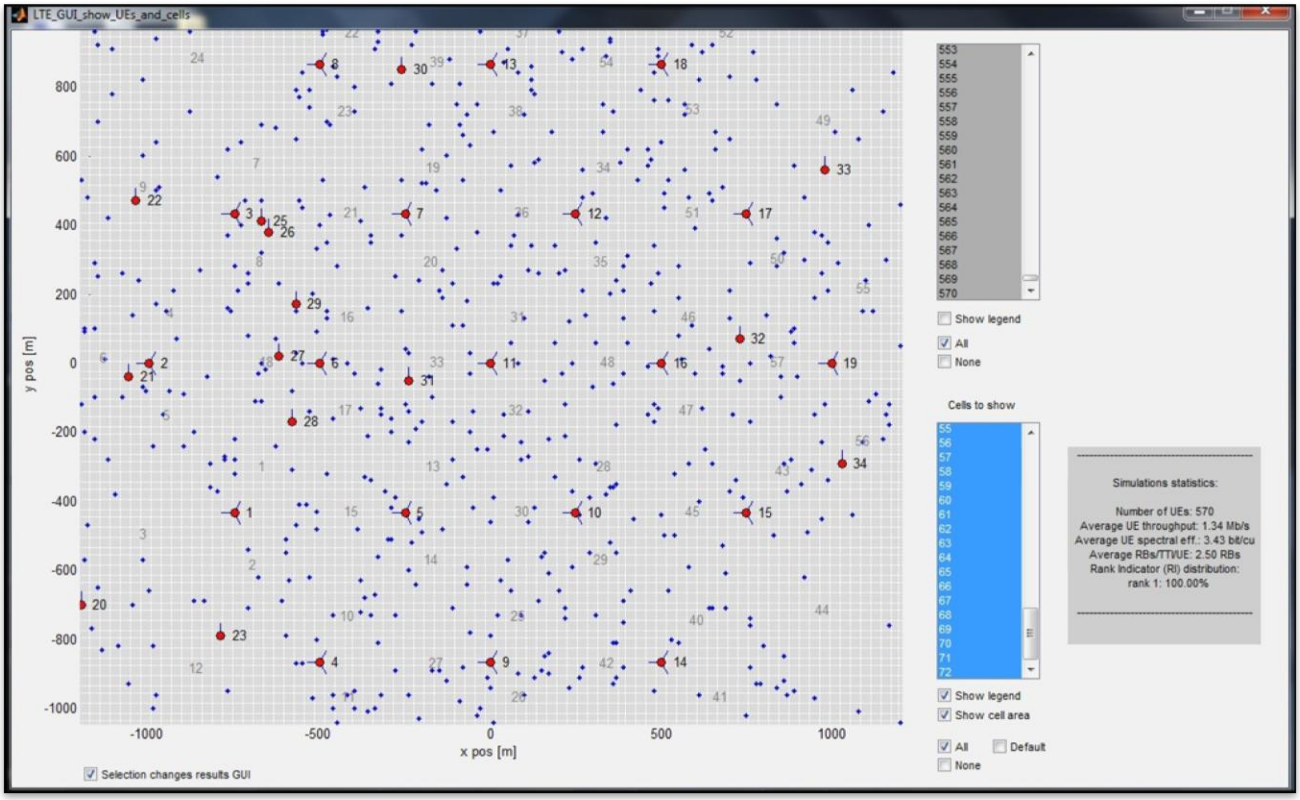


Figure: Distribution of the femtocells and the UEs in a given area

- The small tri-sectored shapes with red dots repesent the femtocells.
- There are 34 of them scattered throughout the ROI randomly.
- They are supporting a total of 570 UEs represented by the blue dots randomly distributed throughout the ROI.

5.2.4 The average UE throughput Vs SINR is demonstrated below:

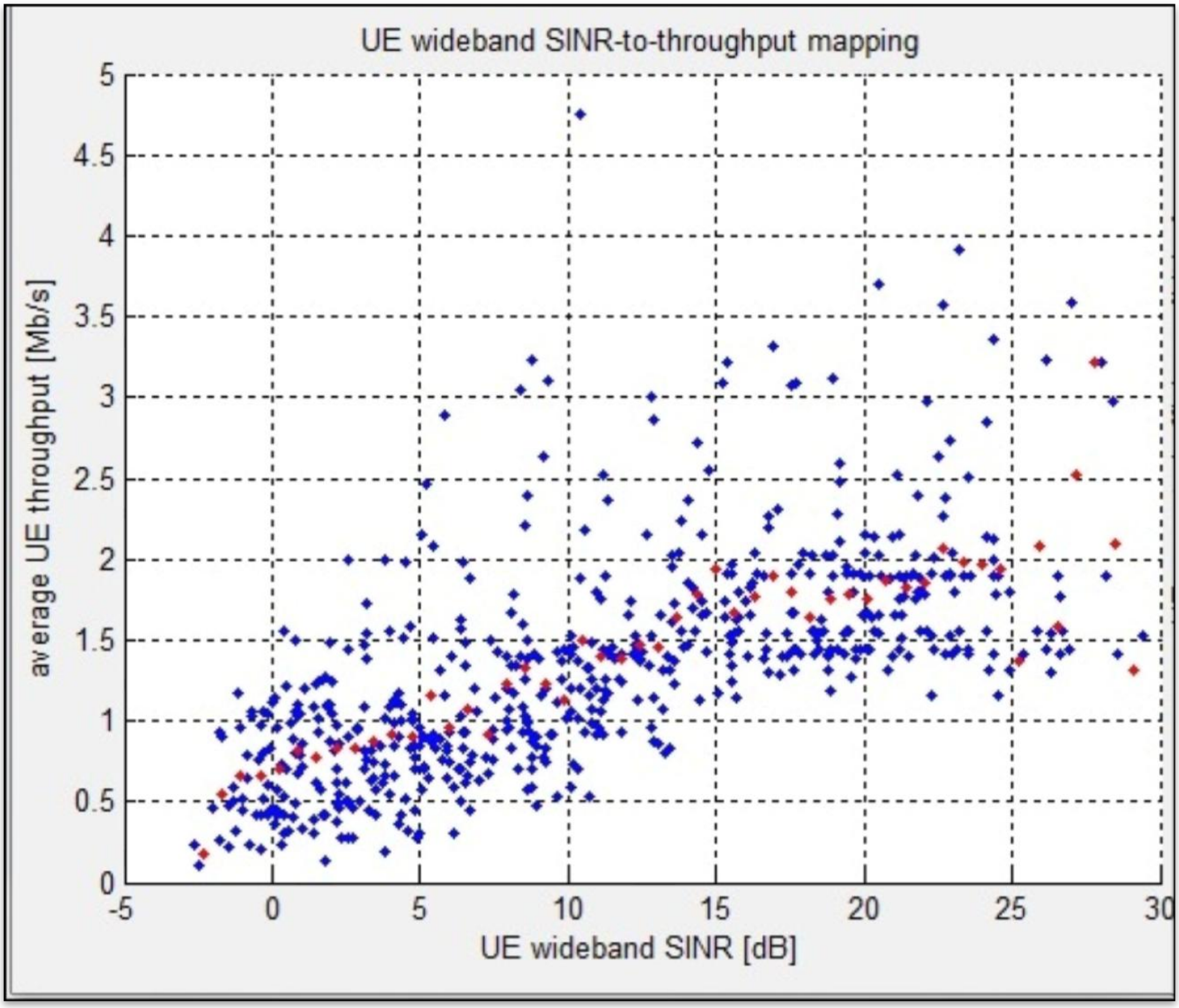


Figure: Average UE Throughput Vs SINR

- In comparison with the Small Cells the average throughput for **Femtocells** is higher which is obvious since we are using more number of **Femtocells** to meet the demand.
- The average UE throughput is **1.34Mb/s.**

5.2.5 The average UE spectral efficiency Vs SINR is shown below:

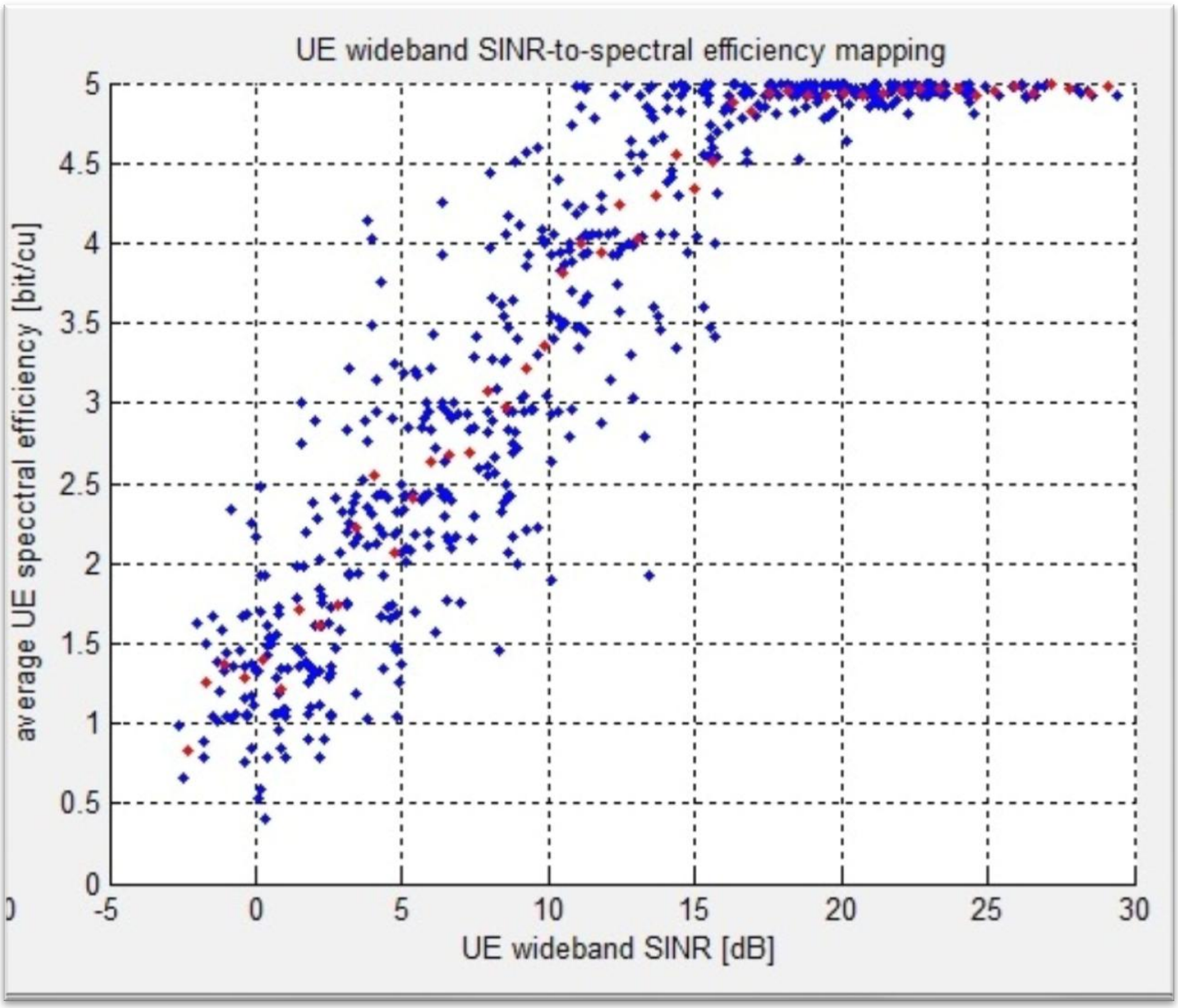


Figure: Average UE Spectral Efficiency Vs SINR

- The spectral efficiency is higher in case of femtocells since the throughput is higher so more data is transmitted over the same channel bandwidth.
- The average UE spectral efficiency is **3.43bit/cu.**

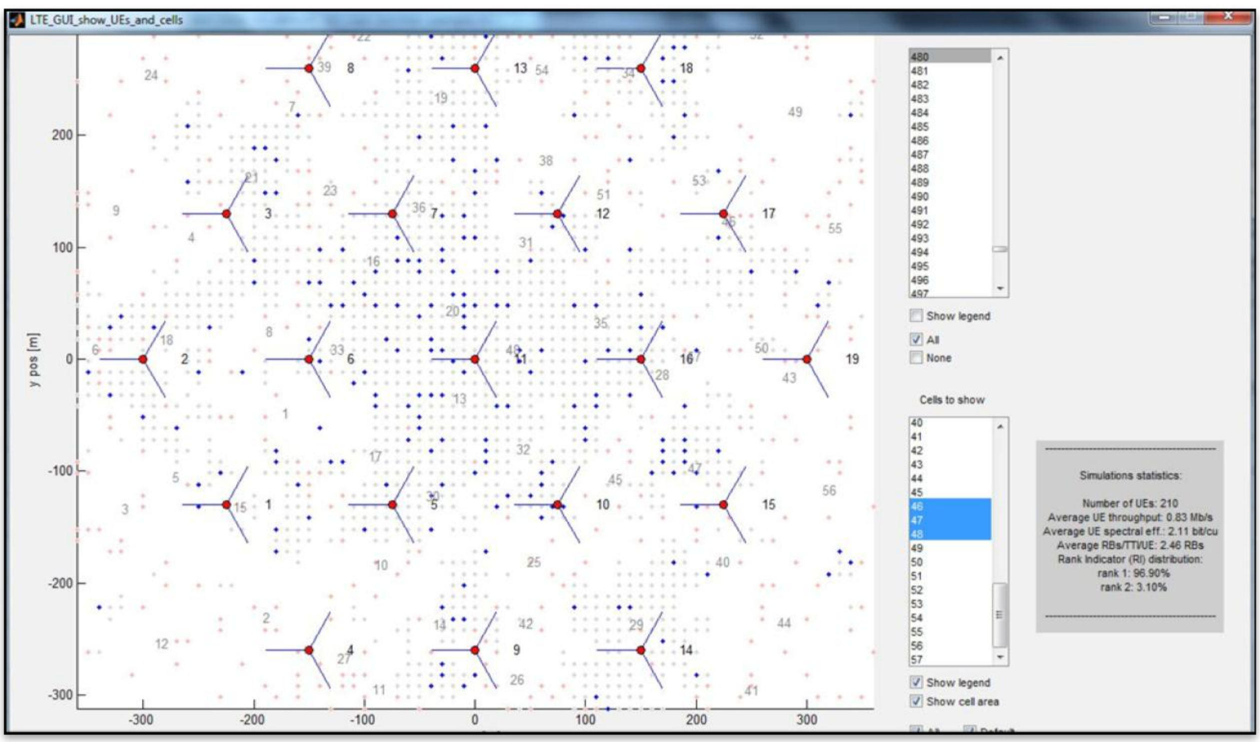
5.2.6 Throughput Calculation:

- Number of UEs = 570
- Number of Femtocells = 34
- Average UE throughput = 1.34Mb/s
- Femtocell throughput = (570*1.34)/34 = 22.46 Mbps per Femtocell

5.3 Performance Analysis Of Small Cell And Femtocell

- In order to make a comparison between the performance of small cells and femtocells we are going to consider the throughput.
- But the area covered by both the simulations was different, so we will estimate the throughput per unit area.
- Thus we can come to a conclusion.

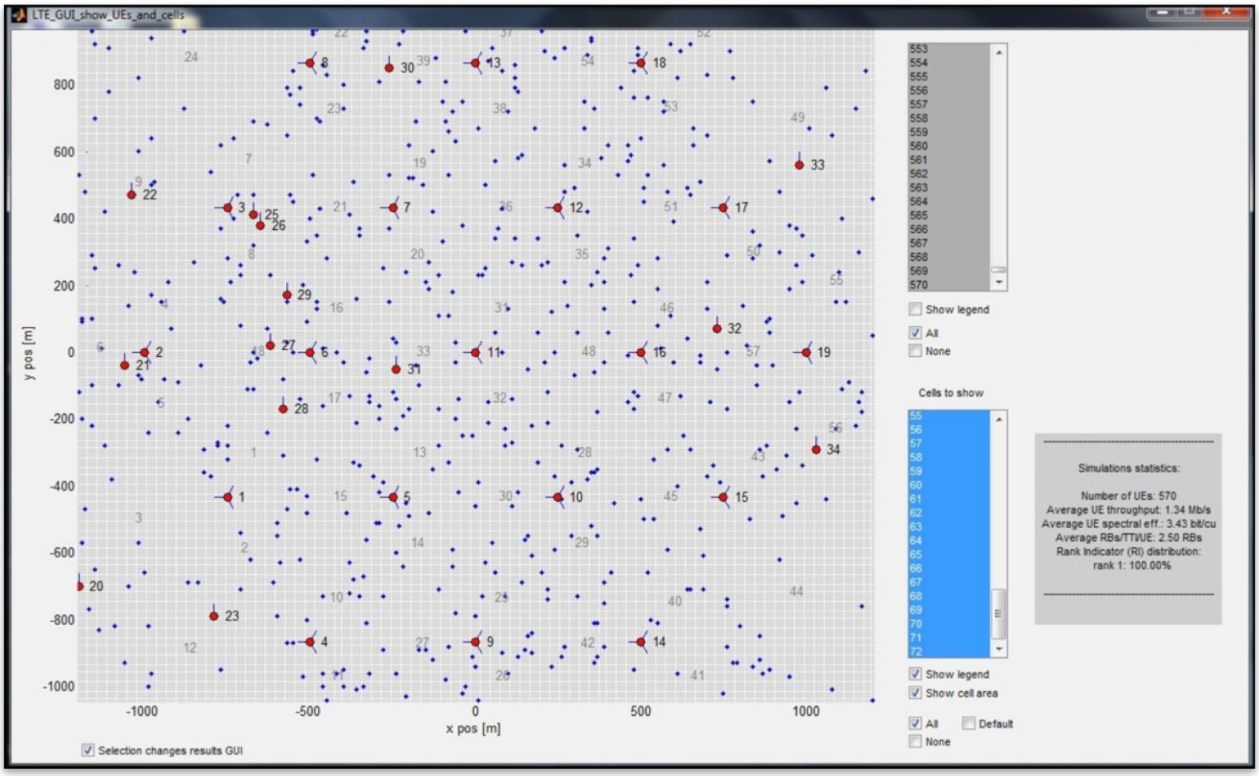
5.3.1 Estimation of Small Cell Throughput



- From the above Figure, we can see that the total area covered by the small cells is equal to 600m*600m = $360000m^2$ = $0.36km^2$.

- Number of eNBs per unit area = 19/0.36 = 52.8 /km^2.
- Throughput per unit area = (210*0.83)/0.36 = 484.17 Mbps/km^2.

5.3.2 Estimation of Femtocell Throughput



- From above figure, we can see that the total area covered by the **Femtocells** is equal to 2000m*2000m = 4000000m^2 = 4 km^2.
- Number of **Femtocells** per unit area = 34/4 = 8.5 /km^2.
- Throughput per unit area = (570*1.34)/4 = 190.95 mbps/km^2.

5.3.3 Small Cells Vs Femtocells

	Small Cell	**Femtocell**
Total Area Covered (km^2)	0.36	4
Average Throughput per eNB(mbps)	27.5	22.46
Throughput per unit area	484.17	190.5
Number of eNBs per unit area (/km^2)	52.8	8.5
Radio planning	Essential, so CAPEX is higher	Not required because it can be deployed at any place (like WiFi).
Interference management	It is vital	Not required
Quantity of cells per square kilometers	Much higher	Limited
Distribution	Geometrical	Random

CONCLUSIONS

- It is better to deploy small cells rather than **Femtocells** in urban areas.

- As the number of **UEs** is increasing rapidly in the urban areas, **Femtocells** alone cannot support the network. That is why **Small Cells** are required to meet the demand.

- It is expected that mobile traffic will increase by 1000x in the next decade.

- This paper presents a highly scalable, low-cost, new deployment **Small Cell** that has the answer to supporting future traffic requirements.

- The model capitalizes on existing consumer sites and backhaul to reduce both **CAPEX** and **OPEX** while allowing significant offloading of users from the macro network, providing huge throughput improvement through cell splitting gains.

- The feasibility of network planning at these high penetrations is questionable, meanwhile the lack of planning can limit user experience if not addressed properly.

Analysis And Comparison Between Performance Parameters Of Small Cells And Femtocells In Long Term Evolution (LTE)

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Finally, we beg pardon and apologize for the faults and any unintentional mistakes that might be recurred in this thesis work even after all the care and precautions were taken.

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