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QUALITATIVE COMPARISON OF WI-FI TO FEMTOCELL (HNB) FOR INDOOR WIRELESS DATA ACCESS

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ABSTRACT

The increasing pressure on spectrum resources of cellular networks has prompted service providers to identify the use of femtocells and Wi-Fi as options for increasing network quality and capacity for indoor data access. This work seeks to make a qualitative comparison of Wi-Fi and femtocell for indoor data access in a Long-Term Evolution (LTE) heterogeneous network, identifying which network access technology serves better for indoor data delivery, using video streaming and Voice over Internet Protocol (VoIP) as services of interest. The performance evaluation was carried out experimentally by using a live Wi-Fi and a Femtocell access point connected via same backhaul. A user equipment with Quality of Service (QoS) parameters measurement capabilities was used to measure parameters of interests from both devices under same measurement conditions for in different indoor scenarios multiple times. We observed differences in the QoS experiences in different scenarios for the access technologies observed, Wi-Fi showed better performance in all of the categories of measurements.

1. INTRODUCTION

Mobile broadband traffic has surpassed voice traffic, and it is projected to exceed 30.6 exabytes per month by the year 2020.[1]

Spectrum efficiency derived from modulation and coding schemes seem to have reached practical limits defined by the Shannon bound. Hence, only limited advancement can be made in this area. Other wireless spectrum efficient technologies are often associated with high cost and technical complexities.[2] [3]

Wireless topologies have also individually fall short of meeting all requirements in terms of user demand. For instance, macro cells has the advantage of covering larger area, hence have a reduced deployment cost. However, macro cells have lesser system capacity, hence, support fewer users. Pico cells, on the other hand, handles higher subscriber density (higher system capacity), but has a relatively small coverage area as compared to macro cells. Femto cells covers even smaller areas but with better subscriber density[2]. Heterogeneous networks suggest overlaying the smaller cells over larger macrocells in areas of inadequate capacity or coverage holes. Also, unlicensed band of Wi-Fi are increasingly used for data offloading by mobile operators.

Studies on cellular networks revealed that 70% of wireless data traffic originates from indoor users [4]. Hence, considering the significant contribution of indoor traffic origins to overall network traffic, it is important to device methods to provide quality data services to indoor users who often get poor networks due to RF obstacles such as walls, wooden furniture and appliances.

Voice only capable networks are normally designed to accommodate poor signal quality, since its data rate requirement is low. Data networks, on the other hand do not tolerate poor signal quality as its data rate requirement is much higher. The requirements for video streaming and VoIP applications are usually more stringent, due to their intolerance to jitter and low Signal to Noise Ratio (SNR) [4]. Hence investigating network access techniques to identify the access method that offers the best Quality of Service (QoS) to users of video streaming and VoIP applications is imperative.

2.0 BACKGROUND STUDY

2.1 Heterogeneous network

The core concept behind heterogeneous network is overlaying low power access nodes on larger access points (macrocell) for data offload, or on coverage holes to supplement macro-cells in areas with high capacity requirements.

Wireless topologies have also individually fall short of meeting all requirements in terms of user demand. For instance, macro cells have the advantage of covering larger area, hence have a reduced deployment cost. However, macro cells have lesser system capacity and, hence, support less user traffic. Pico cells, on the other hand, handles higher subscriber density (higher system capacity), but has a relatively smaller coverage area as compared to macro cells. Femto cells covers even smaller areas but with better subscriber density[5]. Also the unlicensed band of Wi-Fi are increasingly being used for data offloading from the macrocell by mobile operators.

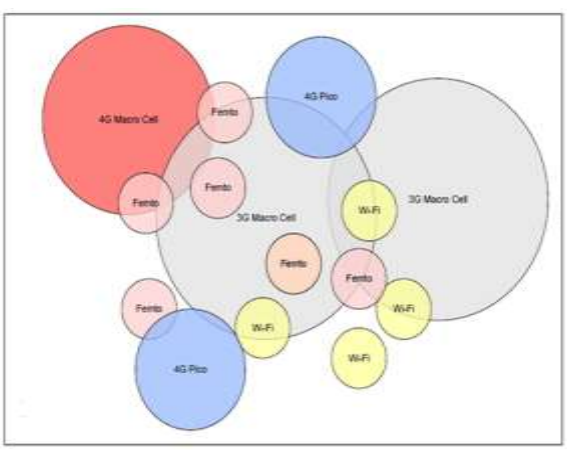

Fig. 1. Overall outlook of a heterogeneous network[5]

Heterogeneous Network proves to be a cheaper and simpler alternative to other spectrum efficient technologies. These smaller cells make heare experienced in areas covered by the low power base stations. Users in the macro-cell experience high performances if there are significant number of hotspots and coverage gap is served by the low power nodes. The performance of low power base stations is dependent on closeness to the point of traffic generation, this makes its deployment more somewhat difficult[6]. It is also noteworthy that due to the small area covered by these low power base stations more of them would be required. Achieving improved performance requires making a proper design and efficient integration of the low power base stations.

Certain factors are considered in designing heterogeneous network. From the demand viewpoint, traffic size, traffic distribution and proposed data rates are important. From a technical view point the important aspects include; radio terrain, the macro-cell coverage area, site availability, backhaul transmission, spectrum and integration with existing macro network are considered. Commercial dynamics, such as technology competition, business prototypes, marketing and pricing methods must also be taken into consideration [7].

2.2 Deployment scenarios

HetNets typically consist of several types of nodes of varying characteristics. For the purpose of defining deployment scenarios, we have decided to group these network components into two groups; the multitier single RAT (Radio Access Technologies) and the multitier multi-RAT network components.

2.2.1 Single-RAT multitier network components

To meet-up with increasing spectrum demands and network coverage requirements, Network Access Points (NAPs) with different footprints and capabilities are strategically superimposed in the same geographical space. In single-RAT multitier network, NAPs operating within same network will employ same radio technology and share the same sets of spectra. The multitier nature of the network improves capacity and coverage through dense reuse of the spectrum and improving link quality. An examination of different deployment scenarios is presented below, ranging from deployment scenarios involving large cell devices to those involving smaller cell devices.[8]

2.2.1.1 Macrocells/microcells

Cellular network base stations' footprints vary based on traffic demand. Macrocells with at least 500m distance between base stations are used to cover rural or suburban areas, while urban areas are covered with smaller radii microcells[8]. Large macrocells has the advantage of supporting high-mobility users,
hence reducing handover frequency.

2.2.1.2 Picocells

Picocells serves relatively smaller areas as compared to macrocells. They are often deployed in high user density areas with inadequate coverage or capacity requirements, such as; stadiums, shopping malls, pilgrimage sites etc. PBSs are typically simpler MBSs with lower transmit power. Their outdoor transmit power ranges between 250mW to 2W [3]. They form part of the operators' deployment infrastructure and are open to all subscribers in its footprint. They make use of same licensed frequency as the macrocells, hence careful planning would be required to avoid cross tier interference.[7]

2.2.1.3 Relays

Relay stations extend coverage footprints by forwarding and improving received signal from BSs to mobile stations. Since relays make use wireless backhaul, operators may choose to employ relays over coverage holes in areas where wired backhaul is unavailable or difficult to implement.

2.2.1.4 Femtocells

FAPs have relatively smaller coverage (10–50 m) as compared to other network access nodes [8]. They are often implemented in indoor locations for improved network coverage. Unlike MBSs and PBSs, FAPs are connected to the network through operator-owned backhauls. In the developed world, FAPs make use of already existing backhaul links such as the Digital Subscriber Lines (DSLs) or cables, hence cutting infrastructural cost. FAPS are usually privately owned and are strategically deployed to serve users with coverage needs. Access into FAPS are usually restricted to certain subscribers in a Closed Subscriber Group (CSG).
FAPs' sharing of frequency with other cell tiers causes interference and consequently limits spectrum efficiency and capacity, which forms the core of our research interest.[3]

2.2.1.5 Client relay

Client relay leverages on device to device (D2D) communication to improve Quality of Service (QoS) of cell edge mobile stations. Client cooperation (i.e., client relay) forms a separate tier in the wireless multi-tier network. It involves a very short link between clients (client cooperation). Client cooperation (CC) exploits the good link between a cooperating client and a BS to "prop" the link of another client that has a poor link to the BS, hence improving the chance of effective transmission. In essence, CC has the potential to reduce the amount of channel resources required for transmission, battery power used and interference experienced in the network. Studies have revealed that CC has the potential to spur average network throughput by a fold of between 80–200 percent.[8]

2.2.1.6 Distributed Antenna System (DAS)

This can also be applied in single-RAT multitier networks. It involves splitting centralized high-power antennas of a base station into smaller low powered antennas placed at strategic locations and all connected to a common processing node via a high-speed transmission media such as the optical fibre cables. DAS has the advantage of overcoming the shadow and penetration loss effect

2.2.2 Multi-Rat network components

Most mobile stations today now have multiple radio interfaces (e.g., Wi-Fi & cellular radio interfaces), which are now being exploited by operators to improve network capacity at a low cost. **Figure 4** illustrates some multi-RAT usage scenarios, and we present some of them here.

2.2.2.1 Wi-Fi offloads

As depicted in figure 4, operators have been armed with flexibility of offloading data intensive traffic from licensed cellular carriers to the unlicensed Wi-Fi hotspot, thereby increasing capacity at lower cost and without compromising on the QoS of parent users of the Wi-Fi Access Point (WiAP) by applying a level of access control on the WiAP

2.2.2.2 Mobile hotspots (personal area networks)

Mobile hotspot are network protocols designed to allow cellular network enabled mobile devices to route traffic from other devices in its premises, hence serving as a backhaul to other mobile devices to the cellular network. Portable devices in the premise requiring internet access would have to connect to the cellular backhaul via Wi-Fi interfaces. Hence, devices connecting the mobile hotspot enabled device requires only a Wi-Fi interface to access the internet.

2.3 Wi-Fi vs femtocell

This section gives general distinction between femtocell and Wi-Fi based on criteria such as system architecture, user equipment specification, frequency band and handover.

2.3.1 System architecture

Femto access point also known as home node-Bs (HNB) are installed in indoor locations for better voice and data reception. Mobile stations are directly connected to the femtocell access point. The FAP is wired to a DSL (digital subscriber line) or cable modem. The home node B is connected to the security gateway which may or may not be integrated with the home node-B gateway (HNBGW). The combination of the HNB and HNBGW forms the home node-B subsystem (HNBS). The HNBS is analogous to the radio network subsystem of a macro access network, as it is directly connected to the core network. It is connected to the Mobile Switching Centre (MSC) via Iu-CS interface and to the Serving General Packet Radio Service (GPRS) Support Node (SGSN) via the Iu-PS interface. The closed subscriber group (CSG) list and administrator server hosts functions for maintaining the CSG membership and access. The CSG list server is connected to the user equipment (UE), while the CSG administrator server is connected to the home location register (HLR) of the core network. [9]

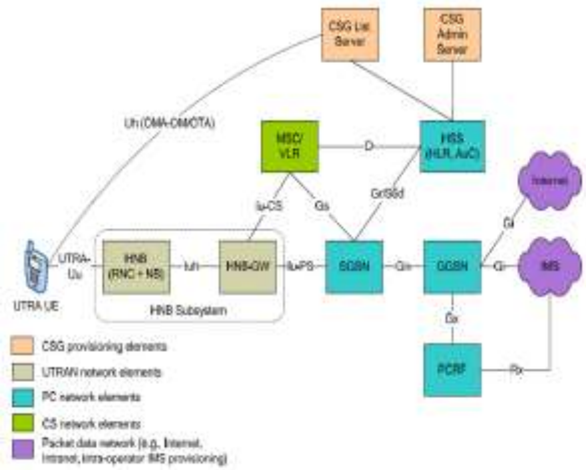

Figure. 2. A depiction of femto cell network integration architecture [9]

Wi-Fi enabled devices are directly connected to the Wi-Fi access point (AP) also called Wi-Fi radio access network (RAN). For every subscriber accessing the network, http communication is used by the various authentication components to verify the authenticity of the subscriber device that is gaining access to the network. The Wi-Fi access gateway (WAG), the portal and the (AAA) server are the basic components involved in the authentication process. When a standalone policy and charging enforcement function (PCEF) is used, the WAG would directly interface with the PCEF for policy and charging control (PCC) implementation. Traffic that do not require policy control can access the internet directly. However, if the PCEF is contained in the gateway GPRS support node (GGSN), the WAG will act as a SGSN and interface with the GGSN via GPRS tunneling protocol (GTP). Extensible authentication protocol (EAP) based authentication requires interconnection between the

AAA server and the HLR. To direct the traffic from the WAG to the EPC via GTP, two interfaces both of which terminates Wi-Fi sessions on the packet data network gateway (P-GW) are required.[10]

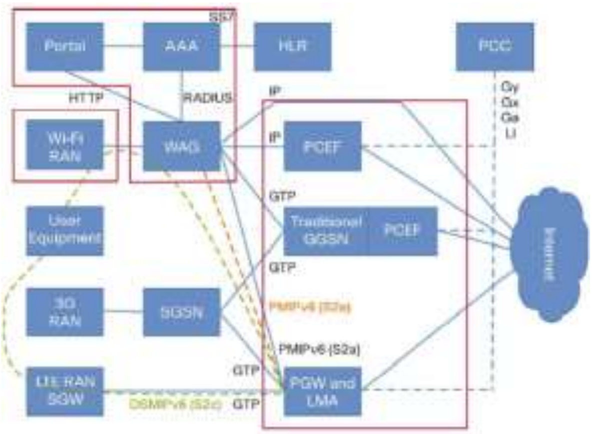

Figure. 3. A depiction of Wi-Fi access network integration architecture[10]

2.3.2 *User Equipment (Handset)*

For femtocells, conventional cellular phones can access it for both circuit and packet services. This is because the femtocell controller serves as an interface between IP and cellular networks. However, devices without Subscriber Identity Module (SIM) are unable to directly access the femtocell for either services.

In Wi-Fi networks, conventional SIM enabled handsets are unable to make circuit switched calls through the Wi-Fi connection, even when they are capable of web surfing. There are other dual mode phones with both SIM and Wi-Fi terminals capable of accessing both femtocell and Wi-Fi connection. Other SIM enabled devices with wireless Wi-Fi adapters are also capable of accessing the Wi-Fi network. [11]

2.3.3 Frequency Bands Used

Femtocells make use of the same licensed spectrum allocated to the operators that owns it. The frequency band employed by a femtocell is deployed either by co-channel frequency deployment or orthogonal frequency band deployment. In co-channel deployment, both the femto and macro cells employ the same frequency band, which in turn generates adjacent channel interference. Orthogonal frequency band deployment is one in which macro and femtocells employ different frequency channels, which in turn leads to reduced system capacity.

2.3.4 Hand Over

UEs in a Wi-Fi cell tend to switch from one access point to another when the Received Signal Strength (RSS) from the home cell is relatively lower that from the new cell by a certain threshold. Due to the small area covered by both femto and Wi-Fi in this case, the possibility of very frequent handover exists, hence the need for seamless handover to enable continuous communication for users. Handovers also occur between Wi-Fi access points and cellular base stations. Here, a dual mode mobile phone switches or undergoes handover as it moves from the access point cell to the cellular cell footprint and vice versa. This is generally known as Wi-Fi offload. [10][12]

Handover between femtocells and macrocells occur when an indoor user moves outdoor (i.e outside the coverage range of femtocell). It also occurs when the users that belong to a femto cell's closed subscriber group (CSG) transit from outdoor to indoor. This type of handover involves a degree of synchronization between the femto access point and the cellular base station, as there is no central management mechanism between the two transceivers. Femto to femto handover is another type of handover that takes place between two femto APs. This occurs when users move between floors of a building served by different femto access points, the user must belong to the CSG of both femtocells. [9]

2.4 Quality of service (QoS)

QoS is the attribute of a packet switched network that enables it to give an order of preference to different applications on the network to ensure quality data flow. QoS as defined by 3GPP categorizes data into four classes; conversational, streaming, interactive and background traffic classes, each having distinct QoS features. [2]

The structure of Wi-Fi QoS includes components such as service differentiation, which involves giving separate values designating priority of channel access to different classes of traffic.

Admission control & bandwidth reservation; which gives channel access based on channel measurement and evaluation, and Rate Adaptation; which involves the variation of data rate in accordance to channel condition.

Femtocells, as opposed to Wi-Fi, might have to deal with a few hardware alterations to deliver the required QoS to users. Employing differentiated media (DiffServ) may present a suitable method of delivering QoS to femtocells, which in turn infers extra bit being encoded for every retransmission. A proposal of Iu+ interface (a result of a change in Iu transport layer) between femtocells and access controllers to deliver QoS over IP network was made by oyster (a communication service provider). [12]

2.5 Network access security

Wi-Fi network access security employs extensible authentication protocol (EAP) and portalbased authentication. EAP based authentication uses 802.11X and EAP to authenticate devices that uses its operator's subscriber identity module (SIM) card that wants to access the network. The device must be EAP capable, as multiple credentials are used for authentication. It provides transparent verification and secured transfer with little or no user intervention. Portal based authentication is used to verify visitor devices trying to access the network. It relies on network connectivity and HTTP for its authentication function. The Wi-Fi access gateway is responsible for access control of IP traffic and denies access to unknown devices until after authentication has taken place. Other modules involved in the authentication process include the AAA server and the portal.[10][12]

In femto access networks, the backhaul to the operator's core is deemed insecure and so a security gateway (SeGW) is implemented to establish a secured link on the backhaul. Some of the security challenges encountered by femtocells include man in the middle attack, denial of service attacks, eavesdropping, replay attack etc. However, apart from SeGW other security procedures include using algorithms with strong cryptography for authentication, device and hosting party mutual authentication, location verification etc. AAA server and HeNB management system (HeMS) also constitute modules required in the FAP security architecture.[9][12]

3.0 RELATED WORKS

[13] explored the feasibility of macro-cell offloading in urban environment using femto and Wi-Fi access points. The study investigates the pros and cons of each of the access technologies under different integration scenarios. The primary aim of the study is to confirm the feasibility of the integration of the small access networks for offload and QoS improvement purpose.

Another comparative analysis of femto and Wi-Fi was done in [12]. The work made a concise comparison between femtocells and Wi-Fi based on architecture, operation and standards. The work identified issues associated with the competing or possibly complementary technologies. It stated that the performance of both access technologies is limited by IP network constraints since both technologies use IP backhaul.

In [14], an analytical model was developed to evaluate the performance of Wi-Fi access points by estimating the number of contending and unidentified nodes that could undermine its performance.

[15] made a performance comparison between femtocell and Wi-Fi based on Simulation using the OPNET simulation tool. The work made extensive analysis of both technologies beyond their capacity crunch. The result obtained shows that Wi-Fi performed qualitatively better for indoor data access. Our research here adopts a more practical approach to compare the two technologies to identify which offers better performance in different indoor scenarios.

[3] Exhaustively explores the challenges associated with possible coexistence of femtocell and Wi-Fi. It particularly investigates the problems that may arise from data offloading between the coexisting technologies

[4] made an advanced comprehensive evaluation of Wi-Fi and Femtocells above the concept of maximum capacity usage, by exploring the indicators of QoE (Quality of Experience) and QoS. The study investigates the possible improvement in user

experience by the hybrid usage of LTE-femtocell and Wireless Local Area Network (WLAN)

In [2] a binary-search based positioning algorithm was developed to optimize wireless indoor and outdoor microcells with respect to different communication environments. This was proposed to reduce the number of access point deployment for a fixed coverage requirement.

Most of the previous work did not make use of the experimental approach which exhibits a more accurate representation of user experience. The result obtained from this approach could be used to develop QoS and QoE models in further works.

4.0 INDOOR PERFORMANCE TEST

The performance comparison test between femto and Wi-Fi access points was done in real indoor environment, in four different indoor scenarios for two different service types (VoIP and video streaming services). A detailed description of the equipment used for the performance test, the test equipment set up and test cases are outlined in this section.

4.1 Equipment used

In the Wi-Fi performance experiment, a Wi-Fi enabled Samsung tablet was used to access a Netgear Wi-Fi access point. For the femto cell experiment, a Subscriber Identity Module (SIM) enabled Samsung tablet was used to access a NEC femto cell access device. Both network access devices were connected to same backhaul for the experiment. The experiments used soft tools accessed or installed on the Samsung tablet to measure and evaluate the performance indices of both access devices. Myspeed.visualware.com was used on the tablet to measure most of the required parameters. Other test tools where used to verify the data obtained from myspeed.visualware.com. The chosen user equipment (Wi-Fi and SIM enabled tablet) was used due to its ability to directly connect to both network access devices (Wi-Fi and Femto).

An exhaustive description of relevant equipment specification is presented in tables 4.1, 4.2 and 4.3.

4.2 Testbed configuration

The Wi-Fi test set up is generic, the Wi-Fi network access device is connected to pre -installed Digital Subscriber Line (DSL). The UE which hosts the performance index measuring tools connects to the Wi-Fi equipment wirelessly for network access and primarily for measurement. Figure 4 depicts the test set-up for the measurement of the Wi-Fi performance index parameters. It is clear from the diagram that the users get data traffic from the radiation of the Wi-Fi equipment. Therefore, the measurement is taken from a wirelessly connected measurement node to the Wi-Fi equipment to have a close indication of user experience.

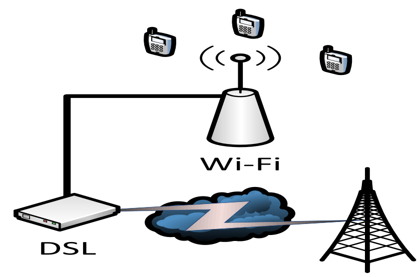

Fig. 4. Wi-Fi Experiment Set-Up

The femto access device is connected to a port on the Wi-Fi device. The Wi-Fi device at this point stops to broadcast or give network access as indicated in figure 5. The femto access point broadcast the network from which the UE can connect and measure performance parameters of interest.

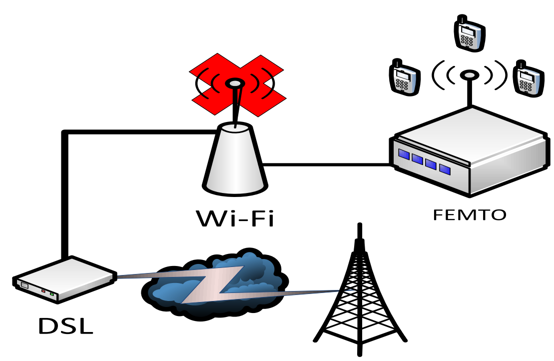

Fig. 5. Femto Test Set-Up

4.3 Test case description

The performance test was done in 4 different indoor case studies. In each case study, femtocell and Wi-Fi indoor performances were investigated by taking measurement of some performance parameters of interest. The access methods were compared for VoIP and video streaming services in indoor location. The aim is to understand the behavior of these access devices in real indoor environments. The different scenarios were arranged to emulate typical indoor environment. The first test set was done keeping the test node in close range to the network access devices, to limit free space attenuation effect. The signal propagation path is deemed to have limited attenuation, interference and no observable obstructions. At this indoor location, the video streaming QoS test was carried out using different soft network testing tools.

A second test case was carried out at 3 meters from both network access devices, also testing for video streaming quality for both femto and Wi-Fi access point.

The third test case was made at 3 meters from the network access device and a 5-inch wooden wall as an obstruction between the access device and the measuring UE.

A fourth test was taken with two wall obstructions, 5-inch each, a total distance of 12 meters from the network access devices with 9 meters between walls, testing for all the different categories.

The aim is to conduct the experiment at practical indoor conditions. The four test scenarios used intends to emulate different indoor usage scenarios.

4.4 Network performance parameters

The parameters used to evaluate the network performance are discussed below.

Throughput: It represents successful delivery message over a unit time between two wireless nodes, measuring by bits/second, Kbits/second, or Mbits/second.

Latency: In the network context, latency typically means how much time it takes for a packet of data traveling from one network node to another. However, in some environment like TCP traffic, latency is measured by Round Time Trip (RTT) that describes the delay calculating by sending a packet to the destination and receiving an acknowledgment from the destination.

Jitter: It describes the variation in the different packet delay, i.e., the time difference between message arrival time. It may be an issue in the voice traffic environment, lower jitter more stable in VOIP communication.

Packet loss: It is also known as drop rate, happening when packets fail to deliver from sender to receiver. It typically caused by network congestion, there is no available wireless medium to send the packet but drop it. Other reason like errors happening during the transmission also could result in packet loss.

5.0 RESULTS AND ANALYSIS

The data presented in table.4 describes the link condition under which the test cases for the Wi-Fi connection were observed. The uplink speed download speed and the Received Signal Strength (RSS) at the end node is measured for each of the test cases under study and presented in the table.

Our observation shows a reduction in RSS value measured at successive test cases away from Wi-Fi access point. A loss of 5dBm was observed from case 1 to case 2, 9dBm from case 2 to case 3 and 12dBm from case 3 to case 4. It can also be observed that the test cases with wall obstacles experienced significantly more attenuation as compared to case 2 which is affected by only free space pathloss. This is predictable as the wooden wall obstacles are expected to have attenuation effect on the RSS and consequently on the data rate obtainable. It can be observed that except for test case one the upload and download speed for test cases two, three and four reduces with increased distance (drop in signal RSS). This is because in adaptive Modulation and Coding Scheme (MCS), higher RSS which could mean better channel condition, gives room for the use of higher order modulation schemes, hence higher upload and download speed. However, as observed, the test case (1) with -46dBm RSS seem to have relatively lower speeds compared to test case 2 with RSS of -51dB, this is because the user/measurement node has gotten sufficiently high RSS with no further gains in speed achievable. In fact, at this point the RSS has reached an unprecedented high value that it becomes difficult for the receiver front end to process it, hence, a drop in physical layer (PHY) data rate is expected. The upload and download speed of the Wi-Fi connection is not showing a significant variation with distance or presence of obstacle as can be observed in the chart in figure 6.

Table 1.Wireless Router Specification

Model	**Superhub (VMDG480)**
Data rate	300Mbps
Number of channels	3 non interfering channels
Encryption	128-bit WEP, WPA2, WPA
Speed (802.11g)	Up to 30Mbps
Interface specification	4 Ethernet 10/100/1000 baseT ports
Antenna	Five internal antenna

Table 2. Femto Access Point Specification

Model	**NEC FP8131T**
Radio Interface	**3GPP LTE band 1 (2100MHz)**
Range	**200m maximum range (10 to 30m indoor)**
Transmit power	**13dBm maximum**
Capacity	**Up to 4 users simultaneously using voice and data**
HSDPA	**Up to 14Mbps, supports category 1 to 12**
HSUPA	**Up to 5.7Mbps, supports category 1 to 6**
Broadband security	**IPsec**
Ethernet	**1EEE 802.3 10/100 Base T twisted pair Ethernet physical connector, standard RJ45 socket, 8 pins, 1 port.**
Interference management	**Fully automatic: real time cognitive radio**
Model	**NEC FP8131T**
Radio Interface	3GPP LTE band 1 (2100MHz)
Range	200m maximum range (10 to 30m indoor)
Transmit power	13dBm maximum
Capacity	Up to 4 users simultaneously using voice and data
HSDPA	Up to 14Mbps, supports category 1 to 12

Table 3. Tablet specifications

Model		**Samsung Galaxy Tab2 10.1**
Memory		16/32 GB internal storage, 1GB RAM, 32GB micro SD
Operating system		Android OS, v4.03 (Ice cream sandwich) upgradable to v4.1 (Jelly bean)
CPU		Dual-core 1GHz cortex-A9
GPS support		Yes – A-GPS support with GLONASS
Data	GPRS	Class 12 (4 +1/3 +2/2 + 3/1 + 4 + slots) 32 – 48Kbps
	EDGE	Class 12
	Speed	HSDPA – 21Mbps, HSUPA – 5.7Mbps
	WLAN	Wi-Fi 802.11 a/b/g/n , dual band, Wi-Fi direct, Wi-Fi hotspot.
Cellular radio frequency band support		2G – GSM 850/900/1800/1900
		3G – HSPA 850/900/1900/2100

Table 4. Wi-Fi connection condition result

Test Cases	**Uplink Speed (Mbps)**	**Downlink Speed (Mbps)**	**Signal Strength (dBm)**
1	1.9796	7.8848	-46
2	1.9816	15.8901	-51
3	1.9794	15.6573	-60
4	1.9711	15.5257	-72

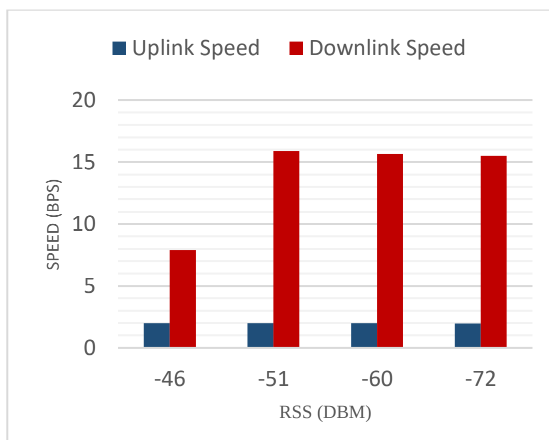

Fig. 6. Link speed variation with RSS for WiFi

From Figure 6, it can be observed that uplink speed is lesser than downlink speed. The common place observation is that downlink traffic outweighs uplink traffic, and it is based on this assumption that operators allocate more bandwidth to downlink compared to uplink at default, with room for adaptation with changes in traffic requirement as developed in [16]. The link speed variation pattern is the same for both uplink and downlink. Table 5 describes the link condition of the femtocell connection. The uplink speed, downlink speed and the Received Signal Strength (RSS) at the end node is measured for each of the test cases under study and presented in the table.

Table 5. Femtocell Connection Condition Results

Test Cases	Uplink Speed (Mbps)	Downlink Speed (Mbps)	Signal Strength (dBm)
1	1.4092	2.6080	-9
2	1.8201	2.7036	-9
3	1.3695	1.6920	-10
4	0.4407	1.2312	-11

Our observation as expected, from the results presented in table 5 is that the RSS measured at successive test cases away from femto access point drops with distance. A similar trend was observed in Wi-Fi. It was also observed that the test cases with wall obstacles experienced significantly more attenuation as compared to case 1 case 2 which is affected by only free space pathloss. This is predictable as the wooden wall obstacles are expected to have attenuation effect on the RSS and consequently on the data rate obtainable.

The uplink and downlink speeds show similar trend as that of WiFi, however, the WiFi link shows a wider difference in up/downlink speeds as compared to femtocell as shown in figure 7. The variation pattern for femtocell link can be observed in table 5.

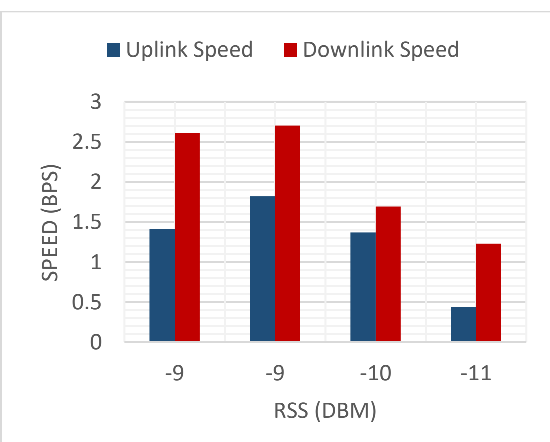

Fig. 7. Link Speed Variation with RSS for Femtocell

It is also clear that the Wi-Fi speed is much higher as compared to the femtocell speed, which can be directly attributed to the to frequency band used by Wi-Fi (2.4GHz) and femtocell (2.1GHz).

The attenuation effect on RSS in the indoor propagation path conforms closely with the indoor Keenan Motley (KM) propagation model.[12]

$$L_{dB} = 32.5 + 20\log_{10}(f) + 20\log_{10}(d) + (N_w XW) \quad (1)$$

where, f is the carrier frequency, d is the distance between the transmitting and receiving node, N_w id the number of walls, and W is the wall constant which is 2dB for plastered wall, as is the case here. The Femtocell connection results shown in table 6.2 indicates a less significant drop in RSS with distance and wall obstacles as compared to the Wi-Fi connection. This might be due to the operating frequency difference between the two technologies. The Wi-Fi operates at 2.4GHz (for the purpose of this experiment), while the femtocell test device operates at 2.1GHz. This is in tandem with the trend predicted in Okumura-Hata (OH) model of pathloss prediction over frequencies and KM propagation model.[12]

The results obtained from measurement of network parameters of interest in the four indoor test cases under study for VoIP and video streaming services are presented in table 5.3 and 5.4, and figure 6.2 and 6.3 respectively.

For VoIP, the parameters observed include upstream jitter, downstream jitter, upstream packet loss, downstream packet loss, Mean Opinion Score (MOS), upstream packet order, downstream packet order and packet discards. Each of these parameters where measured for Wi-Fi and femtocell each for the four different scenarios.

It can be observed from table 6.3 that femtocell connection has more upstream and downstream jitter as compared to the Wi-Fi connection. However, the Wi-Fi connection jitter seem to be constantly rising with distance and presence of obstruction (i.e. as we transverse from case 1 to 4. This clearly shows that jitter isn't necessarily a function of speed or signal strength but more of fluctuation in speed as observed in the plots generated in the visual-ware smart test tool. A depiction of fluctuation in speed in a femtocell VoIP test for case study 2 is shown in figure 8.

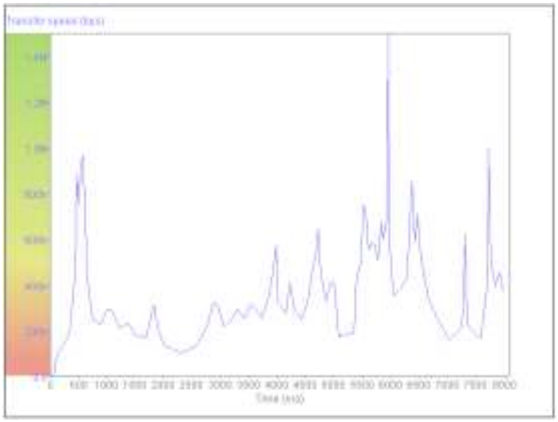

Fig. 8. Visual-ware depiction of uplink speed variation in time for femtocell

Table 6.2 contains the average uplink and downlink speeds for each of the test cases of femtocell taken over the 8 seconds variation. This also applies to the Wi-Fi measurements taken. An excel sheet was generated from the measurement tool. The sampled Instantaneous Speed (SIS) by the tool is used to calculate the Average Link Speed (ALS) shown in tables 6.1 and 6.2.

$$ALS = \frac{\sum_{N_s}^{0}(SIS)}{N_s} \quad (2)$$

Where N_s is the number of samples observed.

Packet loss for both upstream and downstream paths is observed to be uncommon for both Wi-Fi and femtocell. However, Wi-Fi shows greater susceptibility to packet loss as compared to femtocell. The MOS for femtocell is considerably consistent throughout the four test cases, while that of Wi-Fi dropped with distance and signal strength as it transverses the four test cases. Upstream and downstream packet order for both femtocell and Wi-Fi are largely perfect, though downstream packet order is evidently less in order as compared to the upstream packet order. Packet discards are clearly more apparent in femtocell as compared to Wi-Fi, the Wi-Fi connection however showed a 2.5% packet discard in the fourth test case as compared to the 0% discard experienced in the previous cases. This indicates that Wi-Fi relatively withstands obstruction without significant packet discards as compared to femtocell.

Table 6. VoIP test results

Voice over Internet Protocol (VoIP)								
	Case 1		Case 2		Case 3		Case 4	
	Femto	Wi-Fi	Femto	Wi-Fi	Femto	Wi-Fi	Femto	Wi-Fi
Upstream Jitter (ms)	18.6	0.2	13	0.4	28.7	2	3.2	2.9
Downstream Jitter (ms)	12.5	0.2	12	0.2	27.1	2	4.4	2.1
Upstream Packet loss (%)	0	0	0	0	0	17.3	0.2	0
Downstream Packet loss (%)	0.2	0	0	0	0.4	0	0	3.2
MOS	3.7	4.2	3.9	4.1	3.4	1	4	1.8
Upstream Packet Order (%)	100	100	100	100	100	100	100	100
Downstream Packet Order (%)	99.8	100	100	100	99.9	100	100	97.9
Packet Discards (%)	4.4	0	1.6	0	6	0	7	2.5

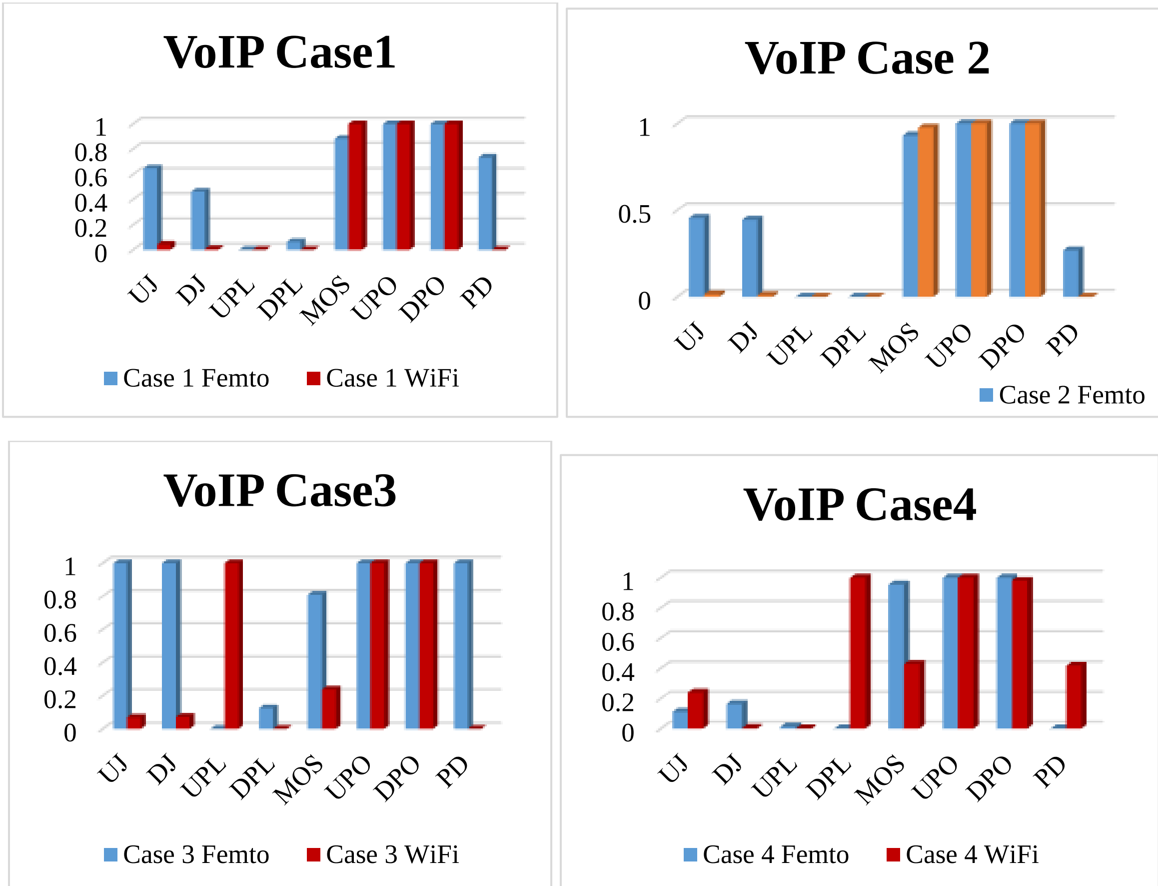

Fig. 9. Graphical Representation of VOIP Results of all Test Cases

Graphical representations of the data observed from the video streaming tests are presented in the figure 10. Since the measured parameters are in different measurement scales each of the parameters were normalized and the normalized parameter value is used to plot the graph.

The video streaming experiment tested for audio jitter, video jitter, audio packet loss, video packet loss, audio packet discard, video packet discard, Round Trip Time (RTT) and video maximum delay for both Wi-Fi and femtocell

From the results obtained, it was observed that femtocell experiences higher video and audio jitter as compared to Wi-Fi. Both jitters also showed a remarkable rise for both femtocell and Wi-Fi connection in 'Cases 1&4' after the introduction of a wooden obstruction. Packet loss (video and audio) was observed after the introduction of a wall obstacle in case 2 and case 4. The Wi-Fi connection has no experience of packet loss in all four test cases. Packet discard (audio and video) variation observed in femtocell and Wi-Fi connections over the four test cases is apparently similar to the packet loss variation observed. The Round-Trip Time (RTT) and video maximum delay observed in the four test cases showed that packets spend more time in transmission on femtocell connections as relative to Wi-Fi connection

Table 7. Video Streaming Test results

	Case 1		Case 2		Case 3		Case 4	
	Femto	Wi-Fi	Femto	Wi-Fi	Femto	Wi-Fi	Femto	Wi-Fi
Audio Jitter (ms)	23.6	4.3	1111	4.5	10.6	4.5	297	5.5
Video Jitter (ms)	23.8	3.2	1281.3	2.7	10.8	3	267.3	4.3
Audio Packet Loss (%)	0	0	72	0	0	0	10	0
Video Packet Loss (%)	0	0	81	0	0	0	31	0
Audio Packet Discard (%)	0	0	98	0	1	0	99	0
Video Packet Discard (%)	3	0	98	0	2	0	99	0
Round Trip Time (ms)	80	32	91	32	110	32	122	32
Video Max Delay (ms)	114	52	126	52	142	52	298	52

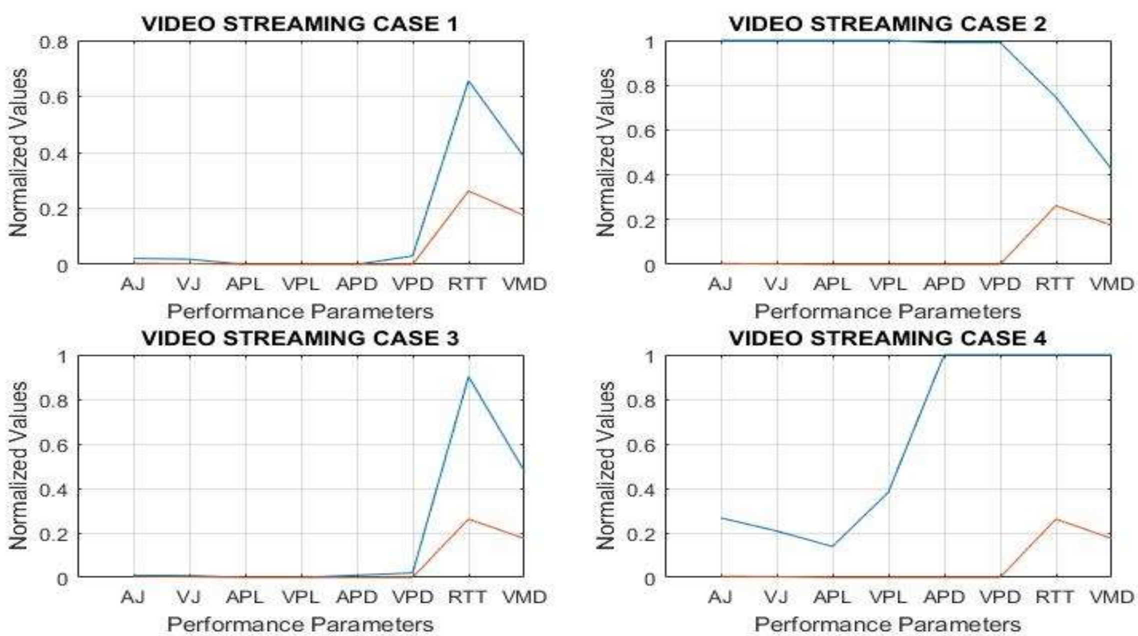

Fig. 10. Graphical Representation of Video

6.0 CONCLUSION

In this study, we have investigated the performance of Wi-Fi and femtocells for data access in LTE heterogeneous network considering four different indoor scenarios using VoIP and video streaming services. A Wi-Fi enabled Samsung tablet was used to access the Wi-Fi access point while a SIM enabled tablet was used for the femto cell access point. For each of the scenarios, the uplink speed, download speed and received signal strength (RSS) were measured. A loss of 5dBm was observed from scenario 1 to 2, 9dBm from 2 to 3 and 12dBm from scenario 3 to 4 which implies a significant reduction in RSS value due to reduction in the spacing (distance) between the AP and the UE. The Femtocell experienced a less significant reduction in RSS compared to Wi-Fi.

In terms of packet drop-in VoIP services, it was observed that femtocell experiences more packet drop than Wi-Fi.

It can also be concluded from our results that femtocell will experience a higher jitter for video and audio traffic than the Wi-Fi. Hence, applications that are highly delay sensitive are best transmitted via the Wi-Fi network while those that are less sensitive to delay can thrive well on femtocell networks.

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