Traffic Management Strategies for Operators

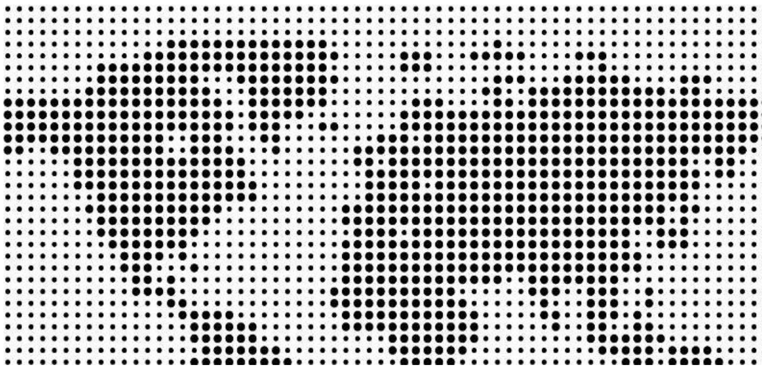

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Table of Contents

[1] Executive Summary

Nearly a decade after its debut, 3G has been widely deployed and supports over a billion subscribers. With the success of broadband, the 3G footprint continues to expand leading to an exponential increase in data traffic demand. The key question now is how can operators meet this demand? There is a limit to what operators can achieve with traditional methods of splitting the macro cells to meet traffic demand.

Today's macro networks are typically designed to maximize data spectral efficiency with a model to service large file transfers. With increased adoption of smartphones and increased number of users on the network, the mix of data applications is changing drastically with numerous smaller transactions leading to a sizeable traffic volume. Interestingly, the traffic volume generated due to smartpones is even without any action taken by the user due to the signaling load.

Also, with increased subscribers and data usage, there are other growing demands on macro networks to prioritize user applications based on aspects such as latency-sensitivity or the need to provide reasonable amounts of data during high load periods. It is essential to manage internal signaling mechanisms and macro network resources intelligently.

Cellular architectures are generally designed to cater to wide coverage areas. User experience typically varies across the cell as the users move far from the base station mainly due to inter-cell interference and other constraints on the transmit power of the mobile devices. There are also known limitations with indoor signal penetration, particularly at higher frequencies. The presence of dead spots in certain areas and terrains exacerbates the problem with drastically reduced indoor coverage.

To address these issues, there has been an increasing interest in deploying small cellular access points in residential homes, subways, offices and other areas where people congregate. These network architectures with small cells (*microcells*, *picocells* and *femtocells*) overlaying the macrocell network are termed as *heterogeneous networks*. These multi-tier networks can potentially improve spatial reuse and coverage by allowing cellular systems with innovative new topologies to achieve higher data-rates, while retaining seamless connectivity to cellular networks.

As the wireless industry looks toward next-generation technologies for enhancements, operators are looking for ways to meet capacity demands in the most cost-effective manner, while managing interference across the networks.

The purpose of this paper is to outline a host of options and alternatives for operators to meet data traffic demand and manage network congestion. This paper provides an overview of various innovations in 3G networks such as the enhancements in connection management, dynamic QoS Control and *SIPTO* techniques to maximize data capacity within the current macro networks to comprehensively meet data traffic demand. The paper also provides an overview of microcells, picocells, femtos and Wi-Fi access points as a means to offload data traffic from macro networks and discusses the applicability of each of the access points for various deployment scenarios.

[2] Overview of the Traffic Management Problem

As the market penetration of 3G terminals increases, operators are witnessing a dramatic growth in data traffic consumption. The success of wireless data services is leading to a capacity crunch. This can be attributed to a combination of factors, namely:

- Flat-rate service plans for data card users;
- Abundance of wireless device applications, resulting in increased data consumption by wireless data card users;
- Increasing popularity of smartphones, along with a plethora of new applications developed for these phones;
- Increasing signaling traffic *overhead*, generated when devices transition between *active* and *idle* states during email and instant messaging, or when the applications poll the networks for updates. The combination of increased data and associated overhead has only worsened the situation.

These factors impact negatively on the user experience in areas where networks run out of capacity. It should be noted that performance gains with the latest innovations may no longer be as promising as witnessed in the first few generations of wireless communications products.

The rollout of new next generation technologies with traditional air interface improvements cannot completely solve the problem, due to limited spectrum bandwidth and the fact that only marginal improvements are expected from spectral efficiency enhancements. The problem not only pertains to the radio access network, but the existing core network designs cannot sufficiently handle the traffic volume at the backend.

To address these issues, operators have an array of options to choose from. One common solution is *cell splitting*, in which the operator simply adds more cell sites or deploys additional carriers. This option does provide increased capacity and eases pressure on the network — but operators can only go so far with cell splitting. The next leap of major performance, however, is feasible by bringing networks closer to the user.

A compelling alternative, which is available to operators today, adopts the concepts of heterogeneous networks, referred to as *HetNets where* some of the data traffic is offloaded onto other networks using microcells, picocells, femtocells and Wi-Fi access points.

While the HetNet techniques hold the potential to boost spectral efficiency per unit area, Het Nets require a basic change in network topology. HetNet techniques essentially enhance signal coverage in localized environments where microcells and pico cells are used to offload data traffic in outdoor environment and femto cells in indoor environments. WiFi access points are used whenever feasible to offload data traffic in indoor environments in an unlicensed spectrum.

As mentioned earlier, one of the important issues operators are facing with increasing traffic demand in macro networks is the growing proliferation of smartphones. Smartphone usage can lead to a significant drain on system resources due to the following.

- Overhead channels are still transmitted even when no data is sent during the active state.
- Signaling messages are sent when there is a *state* transition.

In most cases, efficiency can be improved by reducing the power of the overhead channels and by allowing for small amounts of data, without requiring terminal transitions to active state. To address these issues, changes have already been adopted in the EV-DO and HSPA+ standards.

When data demand is high and traffic cannot be offloaded, operators can prioritize users based on their recent traffic usage. New solutions are now available where operators can use *intelligent scheduling* to ensure that all users receive adequate bandwidth by using QoS (Quality of Service) and by throttling high-bandwidth users during the periods of overload.

The following sections examine the enhancements operators can adopt to alleviate problems arising from increased data users in macro networks and apply strategies with HetNet technology options in localized environments when addressing traffic offload challenges.

[3] Traffic Management in Macro cellular Network

Several innovative, new solutions are available for operators to efficiently manage macro traffic. An overview of these solutions is provided below:

3.1 Innovations in Connection Management

With the advent of smartphones, the mix of applications the macro networks need to serve is changing drastically. There are a large variety of applications running on smartphones, with more being introduced everyday. However, many of the applications share some common characteristics. Much of the traffic on smartphones is generated without any action taken by the user.

Email applications may periodically poll the network to check for new emails or the network may push new emails to the phone upon receipt. Instant messaging and social networking applications will provide updates of presence information about other users from time to time.

Further, devices remain in *active* state for some duration after each data transfer, and will transition to *idle* state after a period of inactivity. In general, the amount of traffic from each application is not necessarily high, but there are generally frequent transfers of small amounts of data.

Connection capacity is hereby defined as the *maximum* number of devices that can operate in a network. Since a smartphone is only in active state part of the time, the connection capacity for smartphones can exceed the number of concurrent connections that can be supported by a network.

The number of concurrent connections in a network can be limited by the quantity of resources such as *spreading codes* or *channel elements*. Devices in active state will consume such resources. As a device transitions from *active* to *idle* state, it can release the resources so they can be used by another device.

When a device is in active state, *overhead signal* (e.g., pilot channel) is being transmitted, which consumes system resources and reduces the uplink (UL) capacity that can be used by others for sending data. This also leads to higher power consumption.

If a device is in idle state when data needs to be transmitted or received, it has to transition back to the active state and this requires a sequence of signaling messages to be exchanged between the terminal and the network. Such overhead messages also reduce over-the-air (OTA) capacity that can be used by other data applications.

The key to increasing connection capacity lies in controlling the amount of overhead. This means reducing the transmit power of overhead signals during active state and also shortening the duration that a smartphone remains in the active state after a data transfer.

The exchange of signaling messages can also be streamlined by using smaller packets, combining multiple messages in one packet and defining new specific messages for users over smaller area.

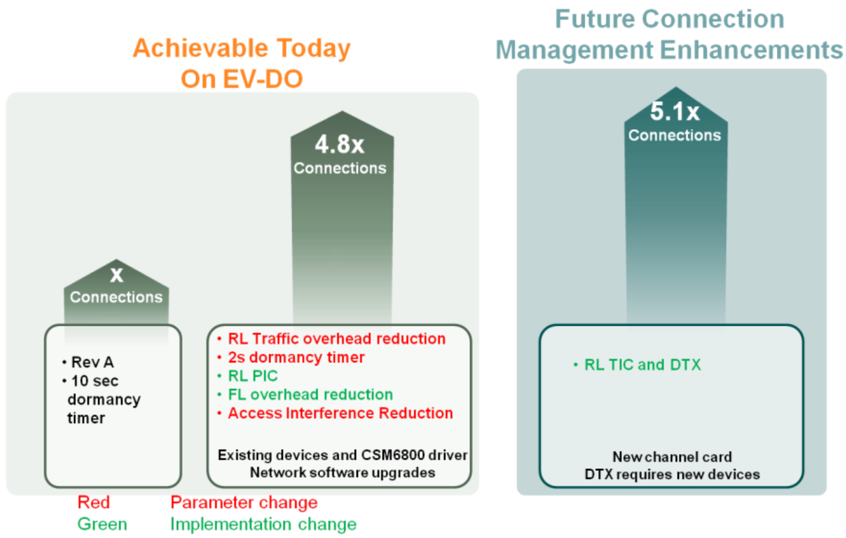

Figure 1: Improvement in DO connection capacity (email & web browsing) with Enhanced Connection Management.

Enhanced Connection Management in EV-DO consists of a number of features that improve the connection capacity of the EV-DO system. ***Figure 1*** shows the simulation results with users running email and HTTP Web browsing on their devices.

By applying a series of parameter optimizations and implementation changes that are achievable on today's system, the connection capacity can increase to 4.8 times of the baseline value. Further improvements are possible when RL Traffic Interference Cancellation and DTX are supported.

3.2 Enhanced Cell_FACH Mechanism

Given that the amount of data to be transferred each time for typical smartphone applications is small, it would be desirable that the devices do not transition to active state for every such data transfer. Not only would this mean lower latency (since there's no need to switch to active state), it would mean that the device no longer ties up system resources, which can then be used by other active devices. This is supported in UMTS by means of Cell_FACH.

When a UMTS device is in active state (Cell_DCH), it consumes dedicated resources such as channel element and spreading codes. Cell_FACH is a *light* state, in which the device can still transmit small amounts of data using resources that are allocated *on-demand,* without having to wait for the transition to Cell_DCH. With UMTS there is also less signaling load involved in moving a device from *Cell_PCH* to *Cell_FACH* than to *Cell_DCH*.

Earlier versions of Cell_FACH have limited capabilities such as low data rate support and lack of CQI/ACK feedback for more efficient transmission. This is being corrected in HSPA+ with *Enhanced Cell_FACH*.

Higher data speed transmission is now supported and CQI/ACK feedback allows more efficient transmission. DTX and DRX are introduced to further reduce battery consumption in the Cell_FACH state, allowing the UE to turn off the transmitter and/or receiver when possible.

With Enhanced Cell_FACH, the network can accommodate more devices running *bursty* applications, and the performance of those devices also benefits from lower latency and longer battery life.

Like Enhanced Connection Management in DO Advanced, Enhanced Cell_FACH does not offload traffic from the macro network. Nevertheless, they both make their respective network more efficient in supporting smartphone/*chatty*-type traffic so that a higher connection capacity can be achieved.

3.3 Dynamic QoS Control

There may not be sufficient resources in the network to meet the needs of all users or applications, unless an effective means of traffic offload is implemented, or extra capacity is added. Thus it is necessary to be able to prioritize applications or users to protect certain latency-sensitive applications or subscribers with reasonable data usage during high load.

On the other hand, when the network is not loaded, the other applications or heavy data users will still be able to consume more network resources. In other words, the difference in priority only makes a difference when there is a *shortage* of resources. This can be achieved by the operator with minimal investment.

The goal is to define a set of priority policies that manage resources intelligently. Non-preferred applications can be put into a scavenger class with the lowest priority (*see **Figure 2***). In the presence of data from other applications, data in the scavenger class queue can be put on hold.

The advantage of this scheme is that the performance of all applications is maintained at a similar level at low network load. When the network becomes congested, the scavenger class applications will see degradation in performance while other applications are affected less (***Figure 3***).

This is a unique benefit of this scheme that utilizes network resources at various load levels. It cannot be done with core network traffic *shaping*, which blindly *throttles* the traffic for applications without taking into account the current network load.

A similar scheme can be used to differentiate users based on their total traffic usage. Sometimes network traffic is dominated by a small group of data-heavy users that generate a tremendous amount of traffic.

Other subscribers, with normal usage patterns, may experience lower data rates or longer latency in the presence of heavy data users. To avoid such a problem, user's priority is lowered when its traffic volume within a pre-specified period exceeds a threshold. At the end of the period, all user priorities are reset to the original level.

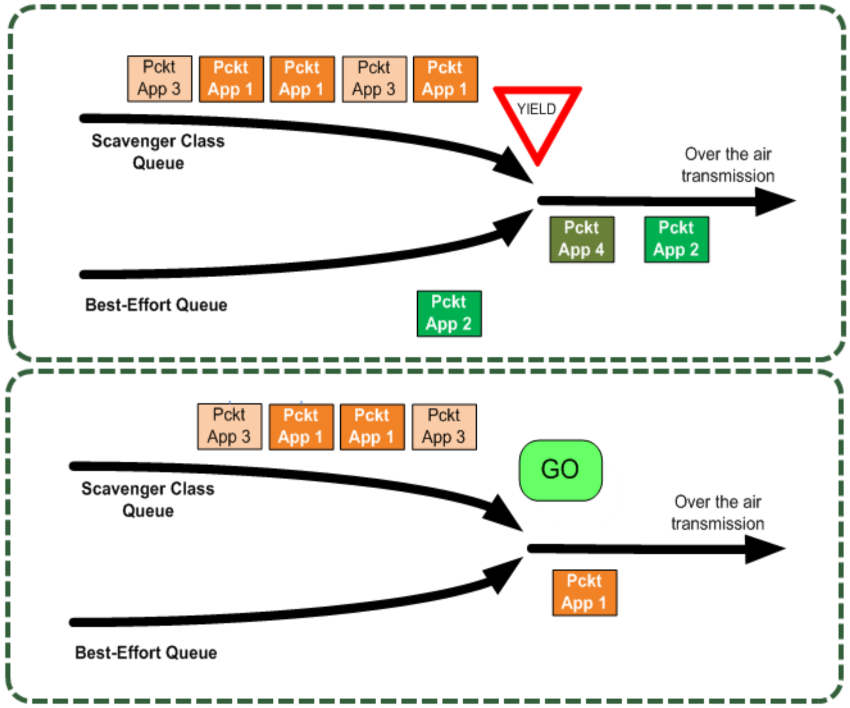

Figure 2: Managing traffic with scavenger class

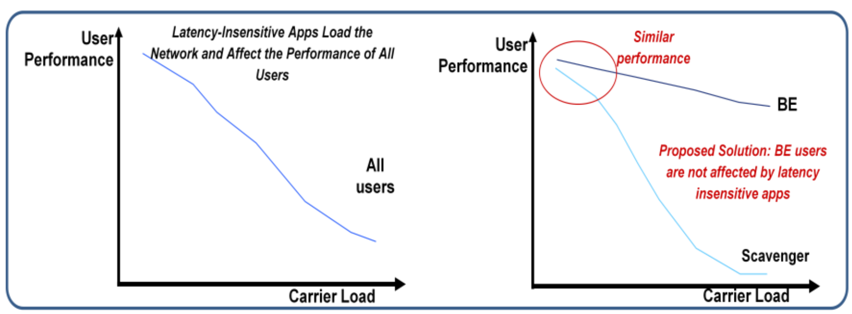

Figure 3: Preserving certain applications' performance during high load by scavenger class

3.4 SIPTO Techniques

Broadband Internet access by notebooks and smartphones constitutes the majority of traffic carried by the wireless networks and drives up transmission costs. *SIPTO* (Selective IP Traffic Offload) mechanisms are intended to minimize the amount of data traffic that traverses the operator's core network — thus reducing the operator's *backhaul* requirements. SIPTO is currently an important item for standardization in 3GPP Release 10.

Figure 4 shows the SPTO architecture where a local GGSN at the RNC assigns IP address UE for traffic that is specifically routed internal to the home network. SIPTO reduces the number of hops required for IP data to reach its destination.

SIPTO provides a number of benefits to *operators**:***

- Reduced stress *on core network nodes* (SGSN and GGSN), which otherwise have to handle increasingly higher traffic from femtocells;
- For *indoor* environments, SIPTO enables high-value services with high application speeds and high quality of service;
- Provides operators an opportunity to reap higher revenues by way of *value-added services* in indoor environments without any additional investment.

For *consumers*, since SIPTO provides an efficient avenue to provide faster and more secure data transfer within the home network, users can enjoy customized, high-speed applications like file transfer, video transfer, device sharing, etc. — without involving the core network. Importantly, SIPTO helps to avoid possible bottlenecks from reduced data rates on the already congested network.

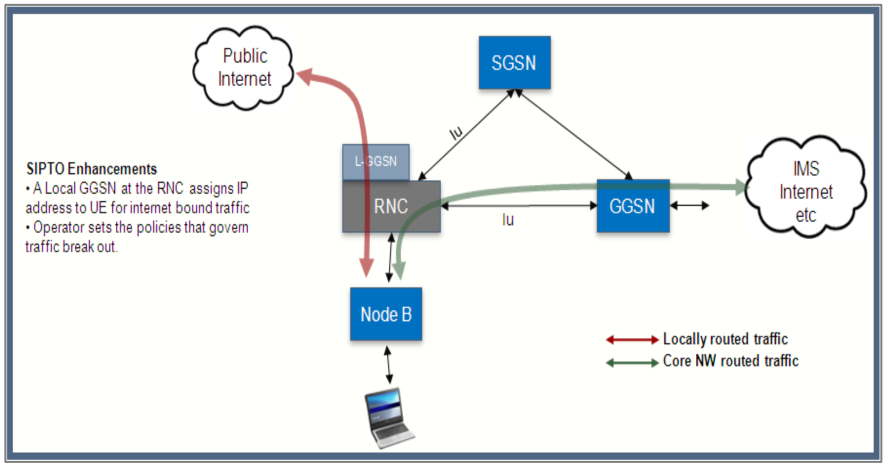

Figure 4: Illustration of SIPTO Architecture showing how it enables routing of local data traffic internally to local GGSN and RNC.

[4] Traffic Offload via Microcells and Pico Cells

Microcells and picocells are very similar to macrocells but are smaller in size, lower in power and are deployed to cover a smaller area and serve users in dense clusters.

Microcells are base stations that connect to the operator's core network and provide additional capacity and coverage. Today's macro cell typically transmits at ~20 Watts. The transmit power range of Microcells and Pico Cells is in the range of 200 mW to 5 W.

Microcells and picocells are relatively simple to deploy – for example, they can be wall-mounted, mounted on a light-pole or erected as a standalone base station, or distributed in a network's architecture with an outdoor DAS. As opposed to macrocells, which cover a wide area, picocells and microcells are deployed to cover a smaller area and serve users in dense clusters.

Benefits: Microcell and picocell users will generally experience higher data rates. The most significant advantages of a microcell come from the fact that it allows co-channel deployments and has limited interference impact on macro users. For operators intending to meet increased data demands in isolated clusters, microcells provide a very efficient means of improving the geometric distribution of users, thus enabling higher capacity gains per sq. km compared to conventional cell splitting. A microcell also offers greater flexibility in site acquisition and enables improved economics compared to conventional cell splitting.

With lower power pico cells, operators can benefit from a scale advantage on the parts used compared to larger power nodes, due to their similarities with handsets. On the other hand, a larger power node provides a larger footprint of coverage compared to a lower power node and hence may require fewer nodes in a given hot-spot. Thus, a flexible approach using a combination of micros and picos is recommended for implementing heterogeneous networks.

Deployment and Use Case Scenarios*:* Scenarios with high user clustering, (i.e., high user density areas) are ideal for microcell placement, thus enabling significant capacity offload from the macro. Microcells are particularly suited for areas of densely clustered users such as malls, food courts, etc. Typical use cases for microcells and picocells are as follows:

- in situations where macrocell requires a coverage extension;
- for data capacity supplements in hotspot areas;
- for extending indoor coverage.

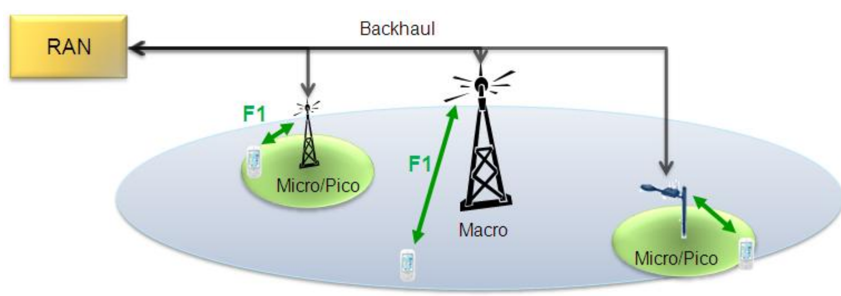

Figure 5: Illustration of a deployment of micro/pico cell in the same frequency channel as the macro.

4.1 Performance Gains with Microcells

The following analysis is based on simulations and can provide operators significant insight on how microcells can be effectively utilized for offloading traffic stemming from the demand from different user cluster concentrations. ***Figure 6*** shows the basic structure of the network layout considered for the simulations.

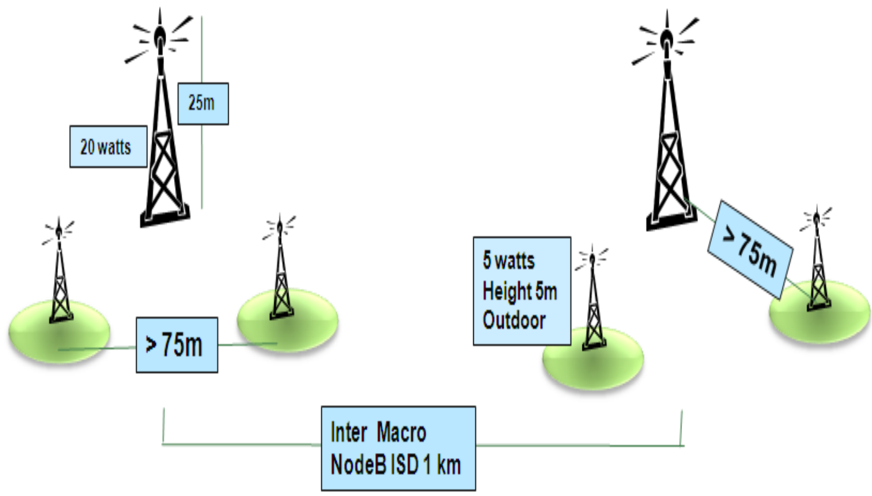

Figure 6: Microcell network layout used in the simulations

Tables 1 and 2 in the Appendix provide the simulation assumptions of the network configuration. Note that simulation results presented in this paper considers microcells with a transmit power of 5W, which is higher than typical transmit power. *Figure* 7 shows an illustration of the different user cluster density scenarios considered for the simulations.

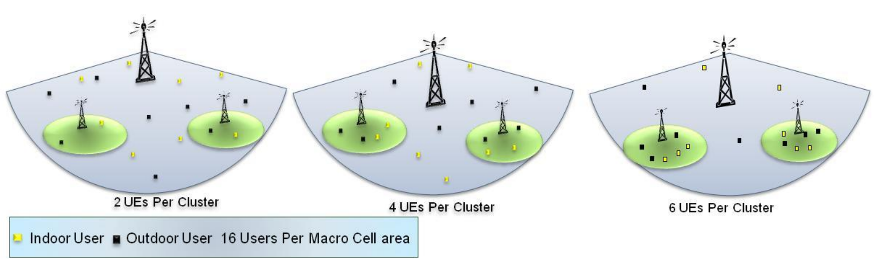

Figure 7: The different user cluster density scenarios, microcell and macrocell network layout configuration used in simulations.

4.2 Analysis

One important result observed is the improvement in the user geometry as microcells are selectively added to a macro network. It is mainly because the geometric distribution of the users covered by the microcells within the macrocell covered area improves tremendously.

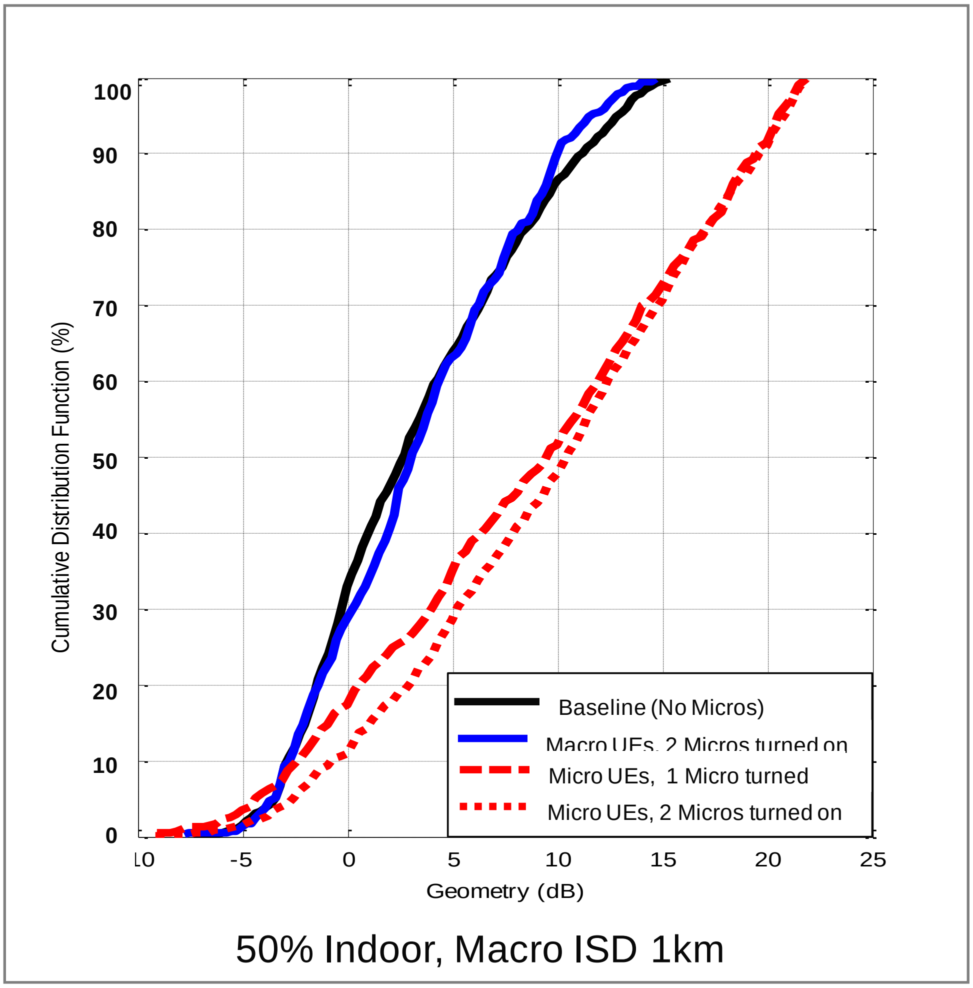

Figure 8: Illustration of the improvement in CDF of user geometry with the inclusion of microcells to a macro network.

Figure 8 shows the CDF of the geometric distribution of users for different scenarios: a) no *microcells b) one micro per macro and c) two micros per macro.*

Another important simulation result is the remarkable improvement in total cell throughput with microcells. As ***Figure 9*** shows, every additional micro introduced into the macro network increases cell throughput by more than 100%. It should be noted that in contrast, cell throughput gains due to cell splitting are largely insensitive to cluster sizes. Also, it was observed that there is an equally distinct improvement in the individual user experience with the addition of microcells into a macro network.

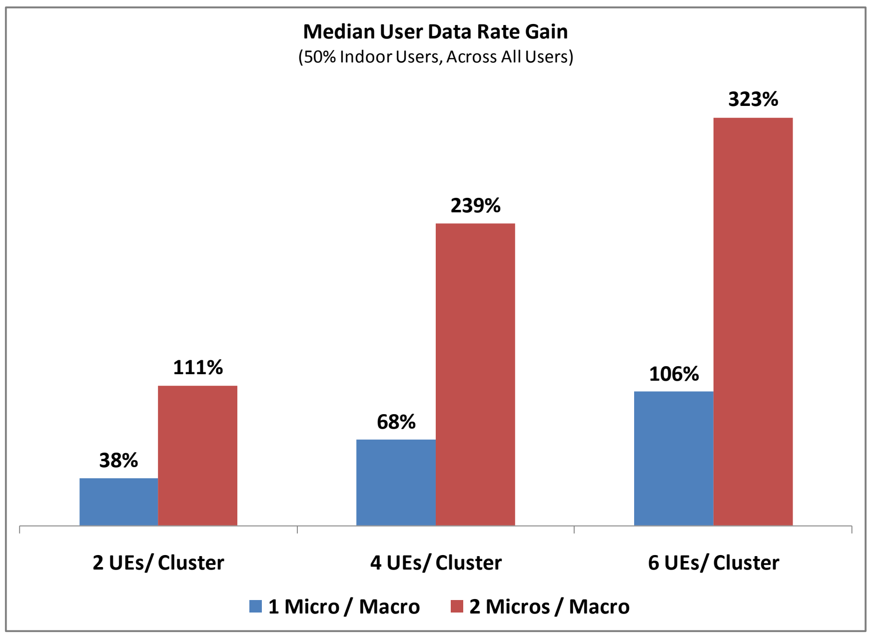

Figure 9: Illustration showing the improvement in system capacity with the introduction of microcells into macro area.

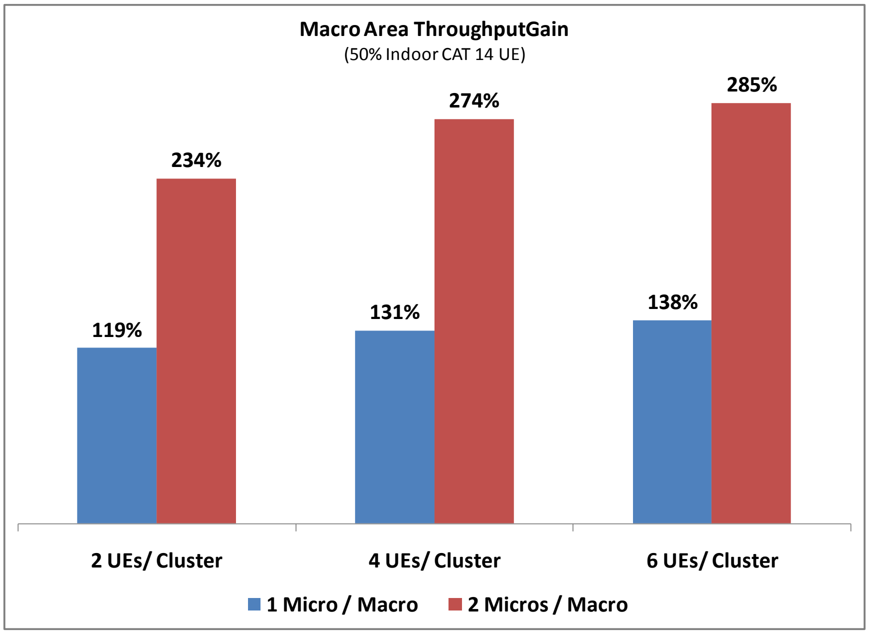

Figure 10: Illustration showing the improvement in user experience with the introduction of microcells into macro area.

[5] Traffic Offload via Femto Deployments

Typically, macrocell sites are owned and operated by a wireless service provider and are connected to the provider's core network via a dedicated connection known as the *backhaul*. Femtos are access points that encompass the base station and controller functions connect to an operator's core network via a gateway and the home broadband or enterprise Ethernet networks that are not controlled by the operator.

Femtos are suitable for indoor settings in both residential and enterprise environments, and transmit at a power level (< 200 mW) that is much lower than macrocells (20 Watts). While femtos serve fewer users, a network of femtos can be implemented to cover a wider area, such as an office building or a big-box store, serving a larger number of users. Femtos can be deployed in an open access or closed access mode.

A key advantage of a femto is that it can readily support existing 3G terminals. Subscribers with femtos receive better signal coverage when they are in the vicinity of femtos and enjoy higher data download speeds compared to macro networks. The other immediate benefit is that the traffic generated by femto users will not be carried over the macrocells and consequently, users on macro cell will have a better experience because fewer users are competing for resources.

5.1 Performance Results

To demonstrate the benefits of traffic offload by femtos, this paper presents simulations for a dense urban scenario. The structure considered is a three-macrocell layout, where there are 75 multi-floor apartment buildings with a total of 2,000 apartment units per macro cell. Macrocell users, served by macrocells, are randomly dropped within the macrocells. Indoor users (home UEs), served by femtos, are randomly dropped in the apartments, with 90% of them being indoor and the remainder being outdoors — on patios.

The simulations are run for three different phases with increasing penetration of users and femtos from *Phase 1* onwards. In all phases, only one-eighth of the femtos are active.

Figure 11 and ***Figure 12*** show higher average DL (downlink) and UL (uplink) user data rates with femtos deployed even when there are more users. Without femtos, the user data rate drops due to the rising user penetration.

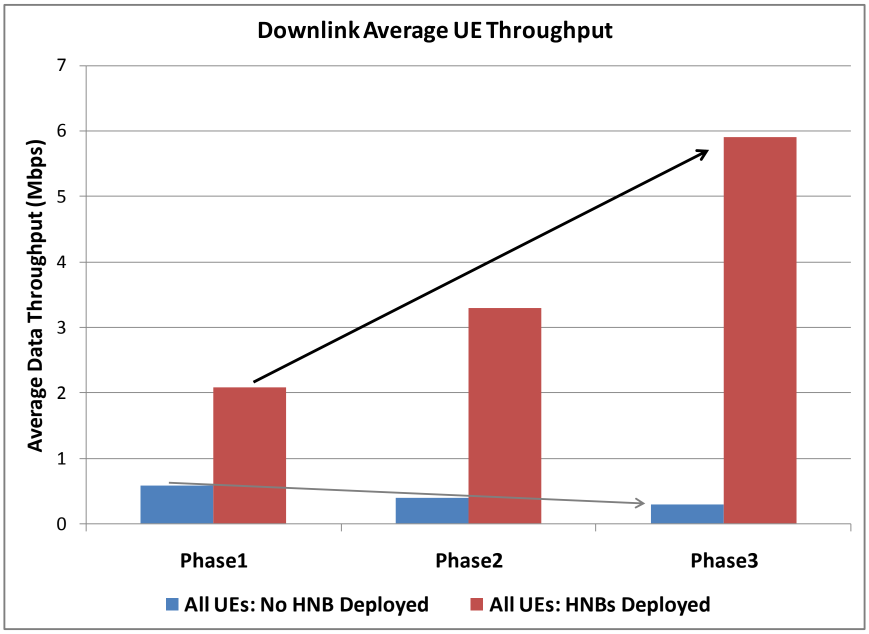

Figure 11: Downlink (DL) user data rate improvement as femtocell (HNB) penetration increases

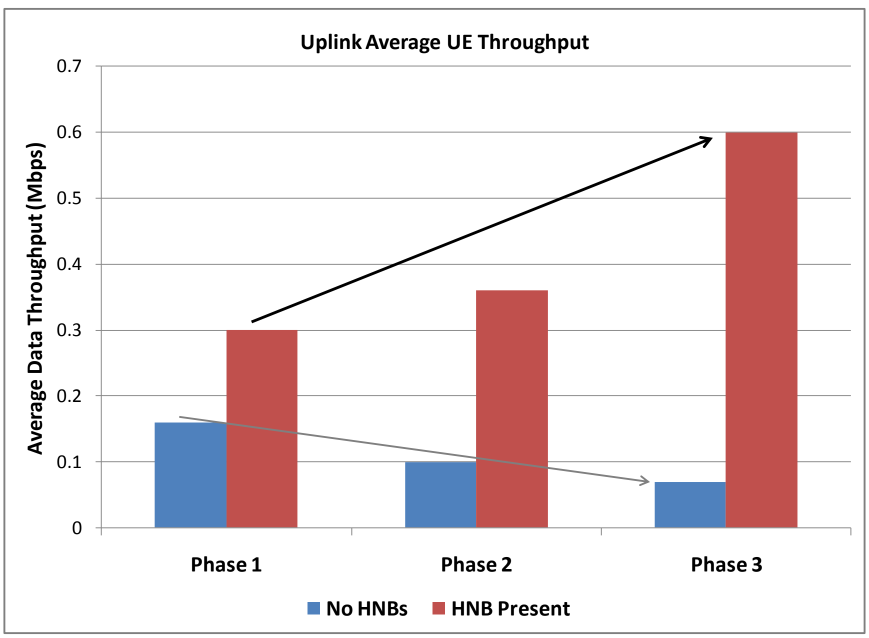

Figure 12: Uplink (UL) user data rate improvement as femtocell (HNB) penetration increases

The simulation results clearly show how the user experience improves with the deployment of femtos. Furthermore, it does not require a high penetration of femtos. In most networks, the traffic generated by users varies greatly. ***Figure 13*** shows that 10% of users download 5 GB or more per month. If this user traffic can be offloaded to femtos, the load on the macro network can be alleviated significantly.

Femtos reduce the traffic on the macro network and provide stronger signals to indoor users, both of which contribute to better user experience and ultimately lower churn. If a subscriber generates a profit of $20 per month, then a $100 subsidy will be recovered when the subscriber remains on the network for an additional five months. If the better user experience results in a higher ARPU, then the breakeven point will be even sooner.

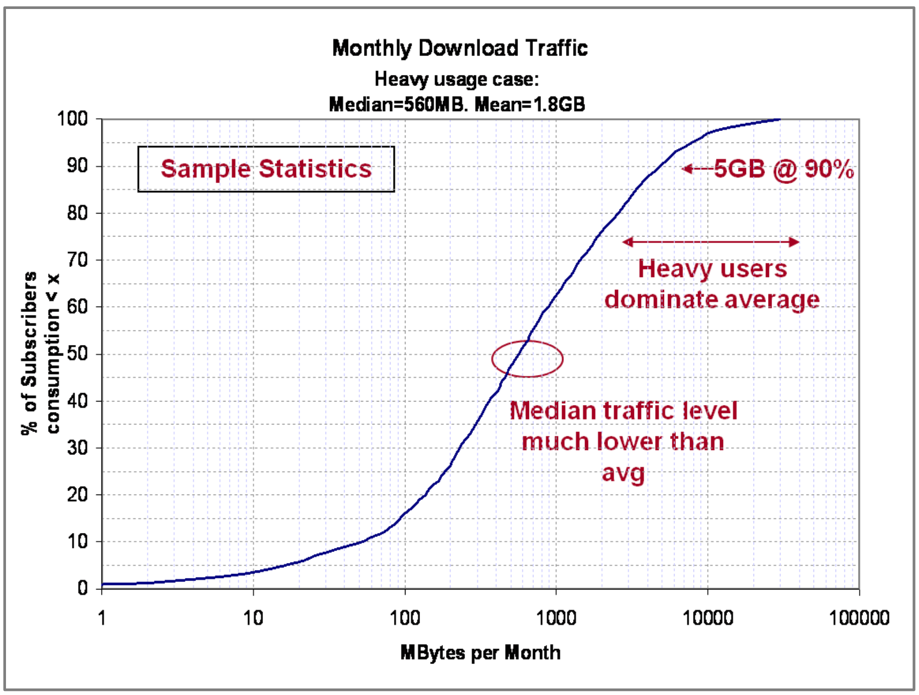

Figure 13: Distribution of user monthly download traffic from commercial network

5.2 Femtocells Key Challenges and Solutions

Introducing femtocells has its own set of challenges, which are mainly due to the following factors:

- Unplanned Deployment: Femtocells are deployed by users without network planning and with no special considerations to traffic demand or interference with other cells. Also, femtocells can be deployed by subscribers in the same channel frequency as the macro networks.

- Restricted Access: Femtocells are basically configured to limit access to only a few authorized users.

Other factors add to these problems. Operators face limited availability of spectrum. RF coverage of femtocells is not optimized by a cellular operator. For all these reasons, there is a potential need to address the following:

- Manage interference between users on macro and femto cells on both uplink and downlink.

- Manage interference between femtocells due to unplanned deployment.

However, if the latest innovations in interference management are adopted, such as those pioneered by Qualcomm's R&D organization, data offloading only gets better with increased penetration of femtos.

5.3 Femtocell Transmit Power Self Calibration

The new interference management procedures enable the femtocell to make DL measurements from macrocells and other femto cells and to self adjust its transmit power, depending on the femto's relative location with respect to a macrocell (cell edge vs. cell site). The new techniques address the potential interference femto users can cause to macro users (and vice versa) and at the same time define a desired coverage area for a femtocell.

One of the key advantages the new techniques offer is to provide the ability for a mobile to easily discover and camp on femtos which in turn helps better traffic offload. This applies even if the femtocell does not offer better signal quality than the macrocell or even if the handset is operating on a different carrier on the macrocell. Enabling in femtocell discovery, a special beacon transmission from femtocells redirects the mobile user to the femto carrier frequency.

The combination of efficient femtocell discovery and interference management methods provides operators a compelling and convenient avenue to offload traffic from macrocells.

Even with these techniques, nodes in the core network (e.g., GGSNs and SGSNs) can still be under great stress. A feature known as LIPA (Local IP Access) can be used to relieve some of that pressure. When a user served by a femto wants to connect to another IP host in the home domain, LIPA allows such communication to happen without going through the core network. In the last two years, there have been multiple commercial deployments of femtos and more deployments are expected in 2010 and 2011.

[6] Traffic Offload via Wi-Fi Access Points

Wi-Fi is yet another compelling option for data traffic offload from the macro network using unlicensed spectrum. Whenever available, the operator can choose to route some or all of its traffic through a WiFi access point. WiFi access points are best suited to seamlessly offload best effort, low QoS data from the cellular macro network.

The 3GPP standards (Release 7) provide an architecture which allows easy interworking between cellular systems and WiFi hostspots. One of the basic components is the SIM authentication over WiFi access points where a UE with a SIM card provided by the operator can connect to any hotspot of that operator or of its roaming partners in a seamless fashion, without requiring user interactions.

The key challenge for a mobile operator is to be able to control which traffic is kept over the cellular access versus WiFi. Simple and standardized solutions are available today to enable operator exercise control over the selection of appropriate applications and service flows based on 3G or WiFi.

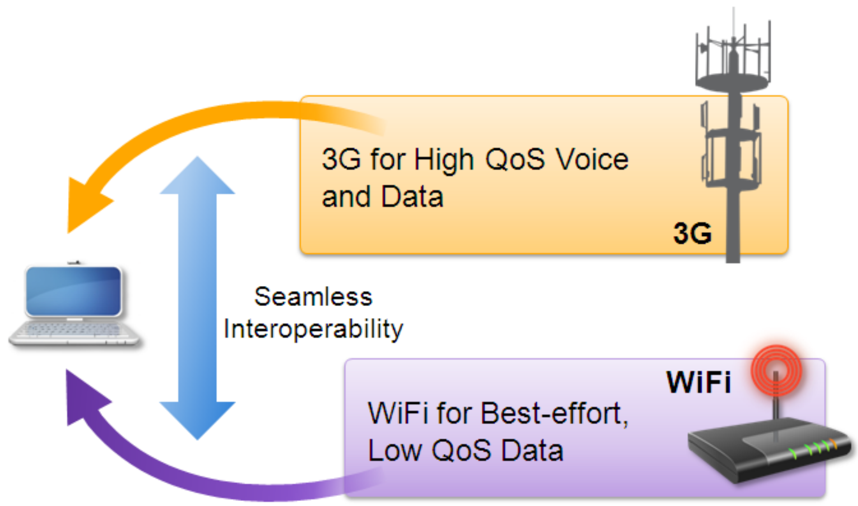

Figure 14: WiFi is best suited to offload best-effort data from 3G networks

An important fact is that currently over 90% of smartphones have Wi-Fi accessibility — Wi-Fi access points are ideally suited for smartphone offload. A key objective for traffic offloading utilizing WiFi accesspoints is to ensure that the transition from the cellular network to Wi-Fi is achieved in a transparent and seamless fashion to the user.

The solution currently implemented by commercial smartphones is based on an application layer switch, based on the assumption that the application will “survive” the IP address change, This however, is very often transparent to the user and does not guarantee a seamless handover to users and operators.

An enhanced Wi-Fi mobility solution is introduced in 3GPP in Release 8, which utilizes DSMIP (Dual Stack Mobile IP). It maintains a continuity of the IP address and thus provides a make-before-break mobile mechanism, resulting in a seamless transition between the cellular and WiFi network, independently of the application being used.

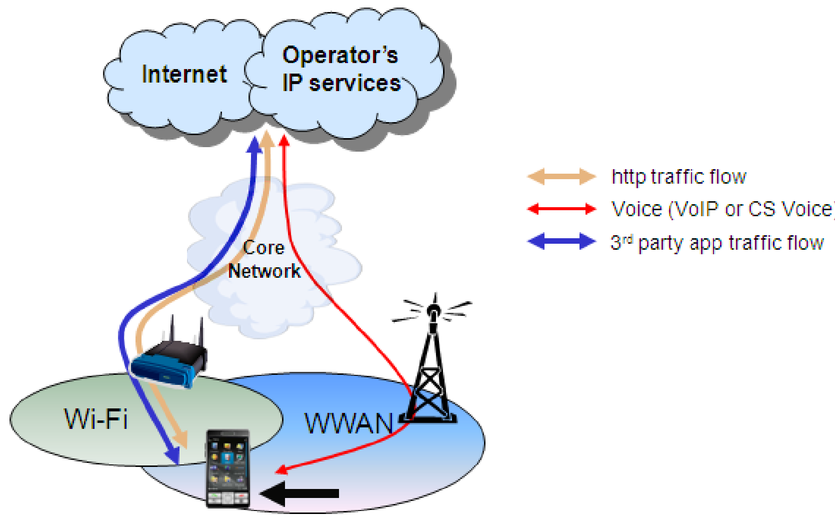

Figure 15: DSMIP Based IP flow mobility enables seamless mobility between 3G and Wi-Fi Networks

Another advantage of the DSMIP solution is that a device can communicate with both the 3G and Wi-Fi networks simultaneously and traffic flows can be dynamically migrated from one network to the other based on pre-determined policy. This is a valuable feature that will be enabled in 3GPP Release 10. Operators can retain applications with stringent QoS requirements (such as voice) on the 3G network to avoid loss/degradation of service while allowing other services to be moved to the the Wi-Fi network to reduce the load on the 3G macro network. A detailed analysis of various solutions providing seamless WAN offload is discussed in reference 5.

Although the offload policy can be determined by the operator, the device is best positioned to make the connectivity decision as it has visibility into both the 3G and Wi-Fi networks. The operator's policy can be provisioned on the terminal or retrieved from the OMA DM server.

Aside from QoS requirements, the offload policy may also take into account the user experience and power consumption when connected to a particular network.While Wi-Fi offload is capable of relieving some of the burden from the macro network, one major limitation is that it can only work with devices that support Wi-Fi. In many markets, there are only a few Wi-Fi-capable handsets. This is in contrast with femtos and picocells which can readily communicate with the cellular devices based on the same technology. Lack of scalability and QoS due to use of unlicensed spectrum are also known challenges with Wi-Fi.

Nevertheless, the availability of low-cost Wi-Fi access points and also the large number of deployed access points are reasons why Wi-Fi will continue to be an important traffic offload option for operators. As operators look to Wi-Fi, more vendors will be developing handsets that support the technology.

[7] Conclusions

Network congestion caused by the rapid increase in data usage is a major cause for concern for many operators around the world. Operators cannot address the problems by resorting to the traditional cell splitting approaches because unequal demands on data bandwidth require a more granular treatment in providing the needed data capacity in a cost-effective manner.

A number of options to offload traffic from the macro network and to increase the connection capacity are presented in this white paper. Each of the various solutions discussed has specific advantages depending on data usage scenarios.

Operators can avail enhancements based on innovative solutions in connection management, enhanced Cell_FACH and SIPTO techniques within the existing 3G macro networks to address traffic offloading. Dynamic QoS control is an expedient solution available to operators where certain latency-sensitive applications or for subscribers with reasonable data usage during heavy network loaded conditions.

For outdoor traffic offload scenarios, the use of microcells and picocells can provide a localized boost in much-needed network capacity for operators. The advantages of microcells and picocells are very compelling as the deployment of these access points blends easily into the existing networks, utilizing the existing backhaul and network architecture supporting handoffs.

As comprehensive interference management becomes part of the solution, femtos can be one of the best strategic options for operators to offload data from heavy indoor residential and enterprise users.

Wi-Fi is another important option for operators wanting to offload traffic in residential and enterprise indoor scenarios. Operators can leverage existing infrastructure to seamlessly offload high bandwidth data using Wi-Fi access points. Although WiFi enables much higher bandwidth, this solution is best suited for best effort, low QoS data in unlicensed spectrum and un-governed service domain.

References

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Acronyms

3G	3^{rd} Generation
3GPP	3^{rd} Generation Partnership Project
ACK	Acknowledgement Field
ARPU	Average Revenue per User
CDF	Cumulative Distribution Function
CQI	Channel Quality Indicator Field
CS	Circuit Switched voice
DAS	Distributed Antenna Systems
DL	Downlink
DSMIP	Dual Stack Mobile IP
DTX	Discontinuous Transmission
EV-DO	Evolution-Data Optimized Technology
GGSN	Gateway GPRS Support Node
HNB	Home Node-B (Femto Cell)
HSPA	High Speed Packet Access Technology
HTTP	Hypertext Transfer Protocol
ISD	Inter-Sector Distance
IMS	IP Multimedia Subsystem
IP	Internet Protocol
LIPA	Local IP Access
OMA DM	OMA (Open Mobile Alliance) Device Management
QoS	Quality of Service
RNC	Radio Network Controller
SGSN	Serving GPRS Support Node
SIPTO	Selective IP Traffic Offload
UE	User Element
UL	Uplink
UMTS	Universal Mobile Telecommunication System
VoIP	Voice over IP
WAN	Wide Area Network
WiFi	Fixed Wireless

[8] Appendix

Simulation framework	3GPP 57 cell wraparound
Number of Micros	2 Per cell, At any time 0, 1 or 2 may be turned ON
Macro Antenna	Sectorized, 5 deg down-tilt
Micro-Antenna	Omni, No down-tilt
Channel Model	PA3 , TU3
Antenna Model	Microcells: Gain = 5dBi, Path loss to Micro-cell = $30.6 + 36.7\log_{10}D_m$ Macro: Ant gain = 16 dBi, Path loss to Macro-cell = $15.3 + 37.6\log_{10}D_m$

Table 1: Simulation assumptions: Network Layout

Cluster Radius	40 m
Distribution (indoor %)	20% / 50% / 80 %
Association	No Restriction: Some outdoor UEs may be served by Micros, Some indoor UEs may be server by Macros
UE Category	CAT14, Some special cases use 8 (discussed later)
Traffic Model	Full Buffer
Penetration Loss	Outdoor UEs have no penetration loss Indoor UEs have a penetration loss (uniform 9 to 30 dB) Model applicable mostly to dense enclosed spaces with few interior walls, areas such as Cafes, Malls, Convention Centers etc.

Table 2: Simulation assumptions for User Clustering and Indoor User Distribution