Scalability Performance of Ericsson Radio Dot System

JOANA VIEIRA

KTH Electrical Engineering

Master's Degree Project
Stockholm, Sweden 29 de Setembro de 2014

Scalability Performance of Ericsson Radio Dot System

JOANA VIEIRA

Master's Thesis at ICT School
Supervisor: Amirhossein Ghanbari
Examiner: Jan I Markendahl

TRITA-ICT-EX-2014:80

Abstract

In the past, network providers resorted to indoor solutions for coverage reasons. However, as traffic volume grows and multiple hotspots appear indoors, capacity provision is also becoming a drive for in-building networks, in particular at the expense of LTE bit rate promises. Network vendors are aware of this reality and multiple indoor systems have been launched, as small cells and active DAS and, in particular, Ericsson Radio Dot System.

A significant factor dictating the system ability to meet future demands is scalability, either in coverage area and capacity. The aim of this thesis is to evaluate Radio Dot System performance regarding those dimensions, where the factors limiting capacity and coverage are addressed added on by a cost analysis. Furthermore, a discussion on the deployment scenarios as a single-operator solution is done on a business perspective.

For the cases evaluated, Radio Dot System provides both LTE and WCDMA coverage and capacity indoors for a range of buildings, from medium to very large. Also, a trade-off between network components and bandwidth allows spectrum flexibility. Moreover, Radio Dot System has an cost advantage over femtocell deployment and macro outside-in coverage regarding the scenarios analyzed. On the other hand, the deployment options as single-operator are, at the moment, limited to medium enterprise clients. However, if the usage of unlicensed spectrum bands, which have been issued in some countries, takes off, more opportunities may arise for single-operator in-building systems.

Referat

Tidigare använde sig operatörer av inomhuslösningar för täckningsskäl. Då trafikvolymen växer och flera hotspots tillkommer inomhus, blir även tillhandahållet av kapacitet ett steg för inbyggnadsnät, framför allt på bekostnad av LTE bithastighetslöften. Nätverksleverantörer är medvetna om denna verklighet och multipla inomhussystem har lanserats som små celler, aktiva DAS och speciellt Ericsson Radio System Dot.

En betydande faktor som dikterar systemets förmåga att möta framtida krav är skalbarhet, antingen i täckningsområdet eller i kapacitet. Syftet med denna avhandling är att utvr̈dera Radio Dot Systemets prestanda avseende dessa dimensioner, där faktorer som begrn̈sar kapaciteten och täckningen utvärderas följt av en kostnadsanalys. Vidare förs en diskussion om installationsscenarier som berör en enda aktör ur ett affärsmässigt perspektiv.

För de fall som utvärderats, ger Radio Dot System både LTE- och WCDMA täckning och kapacitet inomhus för en rad byggnader, som ses som medelstora till mycket stora. En avvägning mellan nätverkskomponenter och bandbredd ger dessutom en viss flexibilitet gällande spektrum. Radio Dot System har dessutom en kostnadsfördel gentemot femtoceller och makro ut-in täckning gällande de scenarier som analyserats. Som ett singel-operatörssystem är driftmöjligheterna för tillfället begränsade till medelstora företagsklienter. Om användandet av licensfria spektrumband som i vissa länder har utfärdats tar fart, uppstår fler möjligheter för enkeloperatörers inbyggnadssystem.

Acknowledgements

In my view, research is all about following the clues that hopefully lead to a meaningful finding that translates to a contribution to the field. I can say that I felt myself on a detective role during the progress of this work and I most appreciate the support of Amirhossein Ghanbari and Jan I Markendahl who have guided me towards a meaningful path through insightful comments.

I am also thankful to my friends who provided useful comments during the various common meetings. A special thanks to Claus Beckman, Bengt Molleryd, Par Tjernström, Tord Sjölund, Carlos Caseiro, Nelson Lourenço, António Lages and João Romão for their availability and useful insights. Furthermore, without the information provided by Peter de Bruin and Sara Landström from Ericsson, to whom I thank for the interest and time, this work would have not been possible with the depth it has.

During this time apart, the support of my boyfriend, Filipe, and my family was most treasured who have always been present, in spite being on the other side of Europe.

Contents

List of Figures

Chapter 1

Introduction

Mobile operators have adopted a variety of business models throughout the past decade to adapt to the technical and social evolution that connectivity has been enabling. In fact, connectivity is one of the driving forces of the digital revolution that has impacted the way people socialize, entertain and work. In particular, the possibility of mobile connectivity is driving an increased appetite for application development and usage which translates to an ever increasing traffic exchange through the operators' networks. The proportions of this demand can be seen from industry and regulators' reports and forecasts on an attempt to identify future challenges and opportunities. As a result, operators' strategies and business models are quite dynamic with regard on how, when and where technologies are used, which services and at what cost are provided and how relations with partners and competition are established. However the main business goal is common to every operator, generate revenue streams and reduce expenditures while providing a recognized value service to continue attracting and maintaining satisfied clients. With the fierce competition of over-the-top and network agnostic services which provide free voice and texting applications and shift the value from core networks, mobile operators need to better monetize their networks offering something more than connectivity and discover new revenue streams. However network upgrades are and will continue to be on the years to come a major concern to mobile operators.

Through providing an enhanced user experience of mobile broadband, indoor solutions can reduce churn and unveil new revenue streams to mobile operators by enabling value-added services due to dedicated networks characteristic. On the other hand, by complementing and optimizing the macro rollout, indoor solutions can allow mobile operators to reduce operational expenses with power and site rental. Moreover, indoor solutions can shift part of capital expenditure to users by incurring investments with equipment and installation to users behalf. As such, if properly deployed, in-building solutions have the potential to drive the total cost of ownership down and help operators to match cost to revenues by decreasing the cost per bit of data traffic.

1.1 Background

Since internet access was enabled on mobile devices that mobile broadband has increasing at astonishing rates. It seams that there is unlimited drive for mobile broadband growth motivated by smarter and enabled mobile terminals, diverse high bit rate multimedia applications, such as video streaming, and increased network performance. The trend is set to continue as Cisco forecasts a mobile data growth of 11-fold (61% CAGR) from 2013 and 2018, figure 1.1.

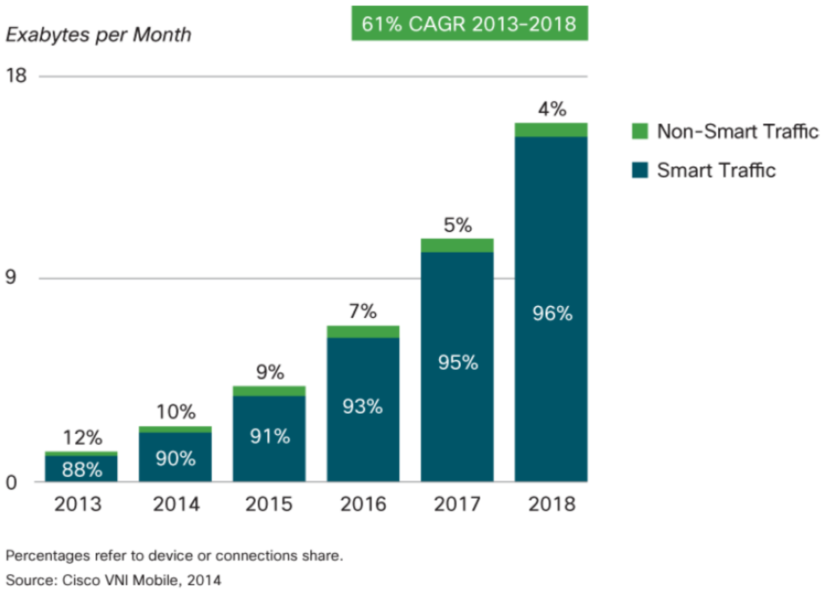


Figure 1.1: Share of traffic per device type.

By 2018, not only there will be an increase on mobile devices penetration but the share of devices enabled with new radio access generations will surpass the 2G terminals, which are still a majority today, figure 1.2. The smartphones, tablets and dongles enabled with 3G and 4G will account for 96% of all mobile traffic, figure 1.1. In fact, a smartphone produces 49 times the traffic of a 2G basic feature phone (10.8 MB per month) whereas a tablet and a dongle produce 2.5 and 4.6 times a smartphone traffic, respectively. The enhanced functionality and support for higher bit rates embedded on new generation terminals motivate multimedia applications consumption such as video streaming and other cloud applications which are set to grow at 64% CAGR until 2018.

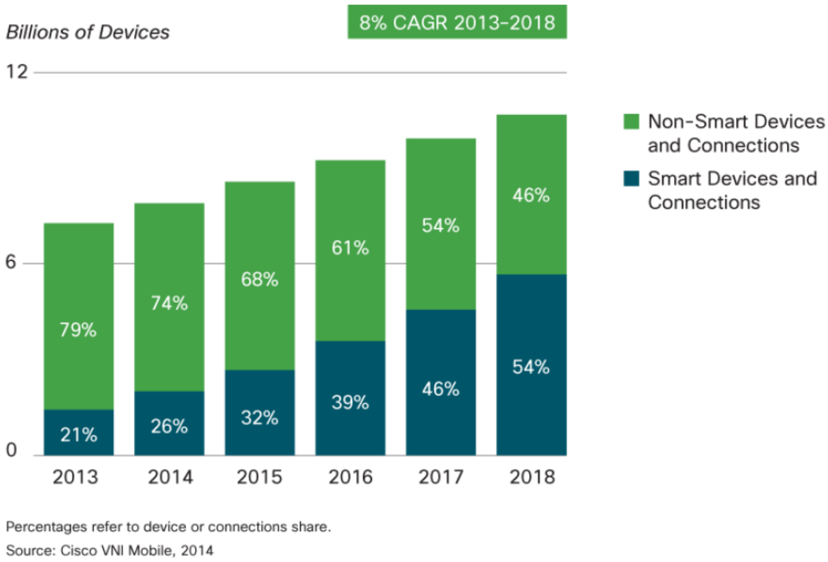


Figure 1.2: Share of 3G and 4G devices versus 2G devices.

On a users' perspective, network performance is perceived regarding the access speed the mobile service provides, which is a significant differentiation factor between mobile operators. As such, mobile operators have been upgrading their WCDMA networks with HSPA and deploying LTE sites to provide higher throughput and make out of access throughput a marketing strategy. The increased bit rate per user and the fast adoption of new generation devices will lead to higher network load levels and operators will be forced to further invest on bandwidth or new sites to cope with the increasing demand. However this traffic exponential growth cannot continue indefinitely, as Jens Zander points out:

"We know from nature that nothing can really growth exponentially forever, at some point we run out of resources. It can be spectrum, energy or most likely money. It is simply too expensive to deploy all that infrastructure to sustain all this traffic. At some point the curve will level out."[1]

It is on mobile operators' hands to push the boundaries by finding strategies to cope with the demand both at the technological and business levels in order to remain profitable in a highly competitive and regulated market. In fact, if mobile operators networks' capacity does not grow at the same rate as demands, these will not be able to materialize. It is a feedback loop, when network performance is enhanced, users tend to increase their usage, and maybe shift from WiFi to cellular networks, thus generating more traffic.

[1]http://theunwiredpeople.com/2014/01/28/jens-zander-on-the-5g-revenue-gap-for-telecom-operators/

The profitability challenge

On cellular networks, the network capacity is shared among users and increased traffic load drives the need for more capacity thus network investments. Such investments on the access network can be recovered by appropriate pricing strategies. In the early days of mobile telecommunications, the value proposition of mobile operators was based on ubiquitously provision of voice services. The most appropriate pricing strategy to recover investments was based on a minute tariff where users would pay proportionally to the generated load on the network. As mobile phones penetration increased and capacity was required, mobile operators could invest on networks with the guaranty that revenues would increase with traffic load.

When data services were introduced, networks could not offer high throughput and, as a result, monthly data traffic consumption was rather insignificant when compared with voice traffic. However, when broadband bit rates (>1 Mbps) where achievable and data applications set off, flat fee subscriptions were applied on a step wise manner to MB and GB monthly level consumption. With such a pricing scheme, the ARPU do not grow proportionally with the traffic load.

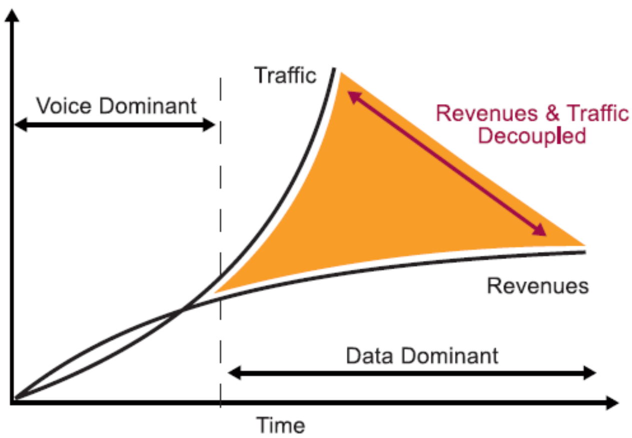


Figure 1.3: Revenue gap.[1]

In 2009, data surpassed voice traffic on a worldwide scale[2] but voice remained the main source of revenues due to the flat fee tariffs. As voice subscriptions stagnate and a shift from a voice business to a data-centric business took place, a revenue gap began to shape, figure 1.3. In a data dominant scenario with increasing demands and network load, mobile operators face a double challenge: maintain steady net-

[2] http://www.ericsson.com/news/1396928

work investments to hold a competitive market position while facing a decreasing profit margin.

Matching costs and revenues

Strategies available to operators to increase ARPU while continue expanding network capacity focus on reducing network costs, new subscription schemes and pursuing new revenue streams [2]. While increasing data subscription prices may increase ARPU, it will not be sufficient to follow the traffic and investments trend [2].

Moreover, broadband provision and internet access enabled over-the-top applications to provide competing services to the mobile operators themselves, as voice over IP, video conferencing and messaging applications. As a result, a mobile applications business continue to grow on top of mobile operators connectivity that rivals traditional mobile services. In fact, such companies are making effort to reduce their distance to users, which are mobile operators' subscribers, by taking advantages of networks features. However mobile operators enjoy a closer relationship with subscribers through SIM cards, which has the potential to generate new service types based on location knowledge and billing relations. Those particularities of mobile operators business can be exploited in order establish new business strategies and services to non-telecom actors and over-the-top application companies while adding new value services to subscribers.

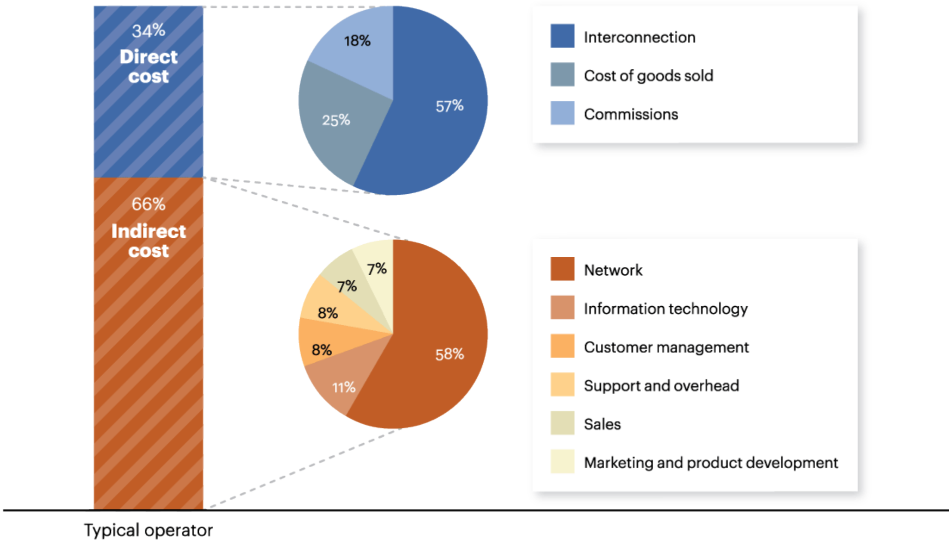


Figure 1.4: Cost breakdown for telecom operators. [3]

[3]https://www.atkearney.com/documents/10192/5b146cc5-2bb0-4ed1-80e0-3344a7f94c8a

On the other hand, mobile operators significant expenditures come form network investments and operation, particularly high license fees and roll-out costs, figure 1.4. As such, investments on network upgrades have a significant impact on the overall business expenditures which require considered decisions on strategies to boost network performance at reasonable investment levels.

Network capacity expansion

Previous radio access generation technologies have been implemented by macro layer deployment to meet the compromises placed by spectrum regulatory authorities on licensed spectrum acquisitions, which would involve a step wise national coverage percentage within the license period. Eventual coverage holes were addressed by microcell deployment, however, with the growth of mobile broadband usage, specific locations require an increased system capacity.

The mobile broadband usage do not extend uniformly throughout the day, figure 1.5 shows the bandwidth demand during the day. The increasing demand on data traffic is translated to bandwidth requirements as it is noticeable on figure 1.5. What is also evident are the peaks of demand, denoted as peak hours. As demand on broadband increases, the difference between peak and off-peak hours accentuates which requires networks to handle high capacity on peak hours and have spare capacity on the remaining period.

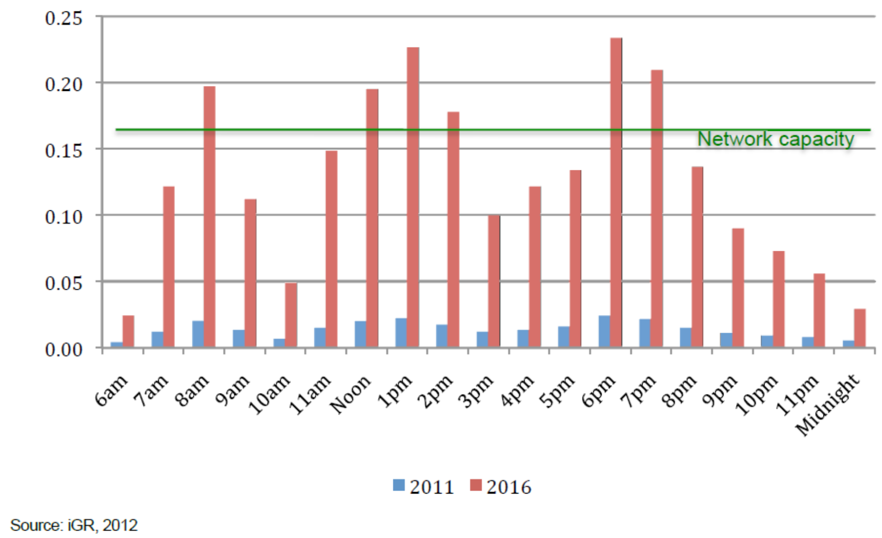


Figure 1.5: Mobile bandwidth demand throughout a day (GB/hour/POP).

Mobile operators usually dimension the networks to address most of the capacity needs but not enough to provide for the highest peak of the day. The green line is a estimated network capacity iGR predicts that a LTE macro network will handle by 2016. It shows that a macro network will not be able to meet the capacity demanded at peak hours and by 2017 macro networks will be able to handle only half of the traffic[4], a macro LTE deployment will not be enough to cope with the traffic increase alone.

Why cover indoors from within?

Traditionally mobile operators have further increase their networks capacity by adding carriers and deploying more sites. In fact, in urban scenarios the macro density is larger than in suburban and rural areas since there is a larger capacity demand due to higher population density. However, in some cases it is not possible to further increase the macro layer density due to regulation restrictions besides requiring high investments and refined interference management. On the other hand, spectrum is a finite and expensive resource that operators manage mindfully and most operators do not have enough carriers to meet demand. An alternative is a different topology approach with networks composed by different cell sizes, allowed by base stations of different power levels. These networks, know as heterogeneous networks or hetnets, integrate different technologies as macrocells, microcells, picocells, femtocells and carrier WiFi to achieve the flexibility to address different hotspot scenarios. Moreover, hetnets provide, in varios scenarions, a cost-efficient solution to offload traffic from the macro layer and increase spectral efficiency while enhancing QoS. One of the most targeted hotspot location is in-building since around 80% of the demand comes from indoors. Moreover, indoor capacity provision is rather inefficient from a macro layer approach since building construction materials can drive path loss figures to levels that do not allow users to achieve the bit rates required for many mobile applications.

Is cellular broadband a reality?

It was not until recently that IP-traffic was enabled in mobile networks when GPRS introduced the packet core network in GSM, which was able to provide a peak rate of 171kbps, followed by EDGE providing peak data rates of 384kbps. However according to the definition of broadband by ITU, only a transmission capacity above 1,5Mbps is considered as broadband and with the introduction of UMTS with WCDMA and HSPA later, which was able to peak rates of 14,4Mbps on the downlink and 5,8Mbps on the uplink, cellular networks were able to provide a truly broadband service. Further enhancements followed on 3GPP Rel-8 which lead to HSPA+ with a peak rate of 42 Mbps on the downlink. LTE is a radio access technology standardized by 3GPP on Release 8 and Release 9, specified together with the Evolved Packet System, an all-IP architecture where the circuit switch core of

[4]Mobile Experts

previous technologies has no couter part. The motivation for LTE development is to provide a packet optimized technology with a flat architecture, where less nodes are required to route the data, that can significantly contribute to higher data rates and enhanced quality of service while enabling cost reduction and a low complexity architecture. As such, LTE allows increased efficiency of radio network usage, latency reduction, improved mobility and potentially lower cost per bit, crucial due to the outpacing of data growth over revenue which is a challenge for operators' profitability. With LTE mobile operators are enabled to offer a mobile broadband experience that rivals fixed-line offerings.

Distributed Antenna Systems - for coverage or capacity?

Distributed antenna systems have been used to provide coverage inside medium to large buildings where signal from outside macro sites could not provide the minimum service requirements needed to establish a connection. The concept of a DAS is to distributed a base station signal over multiple antennas on specific locations. There are three DAS types classified according to the nature of components, passive, hybrid and active. Passive DAS were largely used in the past when coverage was the main driver for DAS deployment. It does not have active components which means that the radio signal is not amplified after entering the system. Bi-directional amplifiers feed a coax backbone in which couplers are used to "tap off" the radio signal for each antenna. The coax transport medium introduces a significant amount of propagation losses which makes difficult to provide high bit rates through a passive DAS, particularly on the uplink. A hybrid DAS uses fiber optical cable between the head unit and remote units which increases signal strength when compared to passive DAS, however, uses coax cable from the remote units to antennas. An active DAS also uses fiber optic between the head end equipment and an expansion hub but uses CAT or CATV to connect to a remote access unit and to the antennas. The losses are greatly reduces and it can be called a zero loss system due to a signal amplification at the antenna point. As such, an active DAS is suitable for capacity provision in large buildings.

Femtocells - towards smaller cells

A femtocell is a low power base station, usually placed in-building, which provides cellular connectivity to the mobile operators' core networks through clients' fixed broadband, via legacy Digital Subscriber Line or optical fiber. By bringing the transmitters closer to the users' terminals it allows a better link quality at a reduced power which means increased transmission speeds and power savings, something that users and mobile operators find quite valuable. The link quality is increased due to a better SINR, signal to interference and noise ratio, achieved by lower levels of interference and noise both on the downlink and uplink, since less users are transmitting inside the smaller cell. Moreover, the propagation loss, which increases exponential with the distance between transmitter and receiver, is significantly reduced allowing for transmissions at lower power levels and, consequently, saving energy costs to operators and the battery of user's mobile devices.

Why not WiFi?

One of the most striking differences between WiFi and cellular is the unlicensed spectrum in which WiFi operates, this means that there is no cost associated with spectrum bands thus being a fairly cheap solution without mentioning the infrastructure already in place. On the other hand, the service quality provided by WiFi is more difficult to manage exactly due to the use of unlicensed spectrum, other technologies operate on the same spectrum band and an overload of users will degrade the users' experience. Unlike WiFi that uses unlicensed spectrum, cellular networks by using operators carrier frequencies enable a more predictable radio network environment where it is much more efficient to deal with high traffic and loaded environments. Nonetheless an operator who has a strategy that makes the most of licensed and unlicensed spectrum to provide the best mobile broadband service is potentially at advantage. An integration of WiFi and cellular coverage on indoor networks is a strategy that addresses that concern and many smallcell and DAS systems which have WiFi access integrated are already available in the market. In fact, this unified access provides a mean to cut expenses with installation, cabling and maintenance which are quite attractive for infrastructure owners.

1.2 Related Work

In this section it will be exposed the relevant work on the three topics the proposed thesis will focus on: scalability of indoor solutions; deployment cooperation indoors; challenges of indoor environments for mobile operators.

Evaluation of several demand scenarios and options for indoor coverage and capacity provision are done by Markendahl in [3]. In particular densification of macro sites, by new deployments and site reuse, deployment of distributed antenna systems and femtocells. Femtocells business cases are explored thoroughly, actors and value networks are exposed for different user scenarios. Indoor deployment solutions do not result in a clear cost-efficient solution, for low demand macrocell site reuse and even new site deployments provide the required capacity at lower CAPEX than the other solutions. However, for high demand, the DAS and femtocell solutions allow high capacity indoors at lower cost in spite the capacity over-provision of femtocells due to coverage limited deployment.

In [4] a comparison in terms of cost is done between deployment strategies involving mix networks of macrocells and smallcells and macrocells and WLAN access networks. Particularly interesting is the cost reduction allowed by a strategy where a HSDPA macro layer is complemented by user deployed access points in open subscriber mode, as a possible case for femtocells.

An analysis on indoor solutions for enterprise capacity provision is done in [5].A financial analysis is done for both indoor technologies regarding the total cost of ownership. It is concluded that for high data rates femtocells are more cost-efficient whereas DAS performs better if coverage is needed instead of capacity.

For the deployment of new radio access technologies as WCDMA and HSPA, mobile operators have been cooperating in order to reduce costs and time to market. Sharing strategies as network sharing, national roaming and dynamic sharing are addressed in [3], where actors and activities in the mentioned sharing models are identified. Also the SAPHYRE project provides contributions on drivers for physical and infrastructure resource sharing as an increased efficient spectrum use.

The slow adoption of cooperation strategies in femtocells deployment is studied thoroughly in [6]. Specific femtocell challenges for indoor active radio access network sharing and roaming are addressed and relevant actors on indoor deployment environments are identified. Also several models for cooperation and outsourcing are proposed according with the role and degree of involvement of each party in the sharing scene.

In [4], the underlining factors of network capacity expansion are identified and elaborated on: competition and demand; coverage and capacity; spectrum and regulations; financial considerations; legacy infrastructure. These aspects allow to pin point the challenges and motivations for mobile operators to deploy indoor solutions as Radio Dot System. These solutions although being the most cost-effective for some scenarios, allow a closer relation to business customers and are a starting point to provide dedicated services.

However issues with spectrum allocation and interference arise, indoor cellular coverage requires licensed spectrum and mobile operators are usually not willing to reserve dedicated bands for the purpose. As a result from the analysis done in [7], spectrum has more value in macrocells than femtocells deployment since the added bandwidth allows an increased deployment cost reduction. As such, new spectrum access schemes are being studied where sharing is an option to reduce the cost of licenses, in particular, licensed shared access (LSA) and secondary access options are of interest.

There are no studies available regarding Radio Dot System cost-efficiency performance on the literature since it is a recent technology. This proposed thesis aims at contributing to the research gap by providing a techno-economic study on Radio Dot System deployment.

1.3 Research Questions

As already mentioned, the research interest is on Radio Dot System scalability and cost-efficiency. In particular, its positioning among other capacity provision options for enterprise environments, as macrocell densification, smallcells and distributed antenna systems. Also, the actors' configuration and which challenges they may face on Radio Dot System deployment are of interest. The following research questions point to the direction of the thesis proposed:

- How are coverage and capacity related for Ericsson Radio Dot System regarding an enterprise scenario?
- How does Ericsson Radio Dot System cost compares with femtocell and macrocell networks on an enterprise setting?
- What are the deployment options for Ericsson Radio Dot System as single-operator?

1.4 Contribution

The academic community has been very active on heterogeneous networks and in-building networks subjects regarding technical and technical-economic aspects. This work aims at contributing to the field by analyzing the in-building Ericsson Radio Dot System on a techno-economic perspective regarding scalability, cost-efficiency and deployment options. Different dimensions and scenarios are looked at and the insights are drawn regarding the scalability performance and the factors affecting it, similarly to other studies in the field for alternative in-building networks. It can be seen as a starting point to build a bigger picture of where Ericsson Radio Dot System will find its place among other technologies and in the market.

1.5 Report Outline

Indoor capacity provision is the main issue addressed in this thesis and in the next chapter the challenges and available options to enhance coverage and capacity indoors are discussed. One of the main considerations for indoor solutions is their scalability characteristics which allow wireless service providers to keep up with the locally evolving demands. A network is scalable when it is able to support an increased number of nodes which translates to a greater coverage area, when supports more users and increased traffic loads and when accommodates different spectrum bands either for different radio access technologies or multi operator service at reasonable investment levels. The remaining of this thesis is focused on these scalability dimensions, where they are divided among the chapters, for three alternative network technologies for indoor provision, with focus on Ericsson DOT, and is structed as follows:

- Chapter 2: The research approach is exposed which is composed by three main components, a feasibility analysis, a techno-economic study and a qualitative study.
- Chapter 3: A study focused on meeting evolving capacity demands regarding monthly traffic consumption, increased user density, amount of bandwidth available and guaranteed bit rate.
- Chapter 4: For selected scenarios a cost analysis is performed by means of a net present value evaluation.
- Chapter 5: Multi-operator and single-operator in-building systems will be discussed from business case stand point.

At last, the conclusions are drawn in chapter 6 by providing an overview of the work done and the main results plus specific answers to the research questions guiding this thesis work.

Chapter 2

Research Approach

In this chapter it is described how the work was conducted in order to achieve the initial goals and get insights towards answering the research questions. The developed analysis comprises both a quantitative and qualitative study so that both technical and business dimensions are accessed. In the following sections those studies are described as feasibility analysis, a techno-economic analysis and a discussion on deployment options for multi-operator and single operator systems.

2.1 Feasibility analysis

To grasp the behavior of Ericsson Radio Dot System, a sensitive analysis is conducted where specific parameters are changed to understand the impact on system coverage and capacity capabilities. Moreover, those parameters are taken to rather extreme levels so that the factors limiting performance are accessed and possible trade-offs identified. The parameters and the rational behind their choice are listed below:

- Coverage area - it is related with spatial scalability;
- User density - it impacts the resource sharing levels within a given area;
- Traffic volume - assumed as a monthly data consumption, it drives traffic load;
- Throughput - assumed as a bit rate, it is related with the level of service provided regarding applications demands.

On real scenario evaluations, these parameters are conditioned by factors such as environment type (residential, enterprise or public), traffic patterns and broadband devices penetration, all closely related with geographic location. On a next step, meaningful values are attributed to the aforementioned parameters regarding real scenarios, where the latter aspects will have an impact.

2.2 Techno-economic analysis

A techno-economic approach is often used to evaluate technology feasibility by taking into account a multitude of factors under technical and business aspects. Such analysis is particularly valuable for network operators in order to aid decision making on radio network deployment strategies by accessing and comparing alternatives[8]. For the matter, several dimensions are introduced as part of specific scenarios, in particular, demand, technical specifications and cost structure which are inputs to network dimensioning and cost modeling. This process output allows a comparison of radio access technologies regarding network architecture, resources, functionality and required investments, figure 2.1.

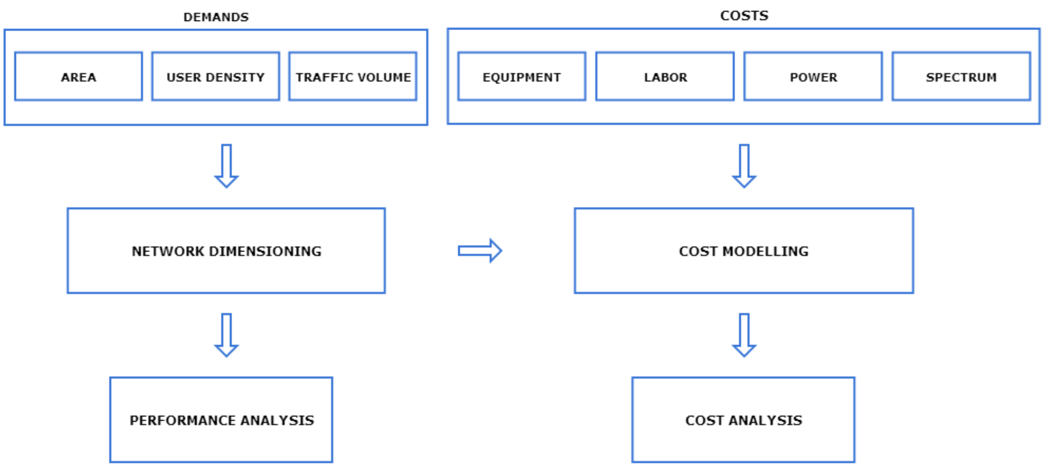


Figure 2.1: Techno-economic modelling.

To address the issues related with the second research question, a techno-economic approach is suitable since it allows a measure of Radio Dot System flexibility to meet actual demands regarding both network architecture and investment aspects. Furthermore, a comparison with other radio access networks provides an understanding of the benefits and drawbacks of Radio Dot System deployment regarding other deployment options for specific scenarios. Other metrics are often added to the techno-economic analysis described to approach the evaluated scenarios of a real deployment scene, such as revenue modeling. This is out of scope but it could be added on straightforwardly.

The particular radio access networks chosen for this comparison were macro site and femtocells deployments, where it is assumed that macro sites can be reused since it is quite likely that operators have sites in place for previous generation deployments. The motivation for this choice is related with the traditional macro approach mobile operators have been undertaking to achieve national coverage which, however, may not provide the required capacity indoors for future demands if enough spectrum is not available. On the other hand, femtocells have been used to fill coverage holes but also allow high capacity levels with low spectrum usage, suitable for scenarios where spectrum is scarce but there is a drive for high broadband demands. However, picocells, passive and hybrid DAS and WiFi are often used for indoor coverage as well but are not addressed in this thesis for particular reasons:

- Picocells have a large coverage area which is not suitable for the indoor environment where walls introduce attenuation between floors and rooms impacting the user broadband experience;

- Passive and hybrid DAS have been used for coverage within large buildings where macro signal was unable to provide minimum service levels, however, the lossy nature of the coax medium used in such systems do not allow provision of high bit rates, particularly on the uplink;

- WiFi is widely deployed but the usage of unlicensed spectrum introduces major drawbacks on QoS provision since those bands are not exclusive to WiFi and operators are unable to manage spectrum usage within those bands.

Scenarios

The focus of this thesis is on Ericsson Radio Dot System which targets medium to large buildings as enterprise buildings, public venues and stadiums where data and voice demands are highest. The techno-economic study described in this report focus on enterprise buildings since those provide a scenario where femtocells are increasingly taking over, particularly on small to medium offices where DAS installation is particularly expensive.[1] In fact, there is a grey area regarding building size where it is not clear which, DAS or femtocells, provide the most cost-efficient solution.

The main driver for in-building cellular network deployments has been voice coverage but as next-generation radio access technologies accustom users to high bit rate applications, the drive for broadband experience indoors increases, particularly considering that OTT voice and video applications are being widely adopted. As such, LTE deployment is the focus on this study even though VoLTE is taking its firsts steps and voice services are provided through a fall-back to 3G technology. Nevertheless, Ericsson Radio Dot System enables both WCDMA and LTE to a certain coverage extent and 3G/4G multimode femtocells exist in the market while 3G femtocells still are the most adopted.

[1] ABI Research

Data Collection

The inputs for the techno-economic analysis seen in figure 2.1 were collected from several sources which are pointed out in this section.

Building Settings

To gather significant values for enterprise office area and number of users, a business district in Sweden, Kista, was taken as example. Several plants of enterprise buildings pertaining to Kista were collected to gather the required parameters.

Traffic Volume

Companies and regulators often analyze the telecommunications market to identify trends and, as a result, produce periodically reports with statistics about traffic usage. In particular, two reports provide relevant information on mobile broadband usage to this study:

- Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2013 2018, Cisco;
- The Swedish Telecommunications Market, first half-year 2013, PTS.

The data collected from this reports regards the monthly broadband consumption of enterprise users and the increase on busy hour traffic. Both Cisco and The Swedish Post and Telecom Agency (PTS) distinguish business from private consumers through the payment entity. If it is a enterprise then the traffic is considered from a business source. However an amount of this traffic is probably generated outside the enterprise building. On the other hand, personal devices which do not belong to the enterprise subscription can be used inside the buildings. These situations will not be considered.

Some data was not available for the period which was intended to be evaluated therefore a forecast is made based only on CAGR for previous periods. Equation 2.1 is used to compute the CAGR while equation 2.2 is used to forecast the future values.

$$CAGR = (W_i/W_0)^{1/i} - 1 \tag{2.1}$$

$$W_i = W_0(1 + GAGR)^i \tag{2.2}$$

Where W_0 represents the initial value, W_i the forecast value and i the period of forecast.

Cost Structure

The inputs for cost modeling are the cost for radio elements, cabling, labor work and power which were based on literature and industry sources. As Radio Dot System has not been commercialized yet, therefore, the price of components is not yet known. For the purposes of this study, the price of components was based on DAS components' cost found in the literature.

Network Dimensioning

The network design is heavily dependent on the radio access system in question and the demands, which are an input to the model. Furthermore, the network dimensioning can be done by assuming overall parameters or by running detailed simulations, the first approach is taken in this study since insights for a broader set of parameters are in line with the objectives rather than a detailed scenario description.

The objective of network dimensioning is to get details on the network components required according to the input demands. Such components are base stations, cabling, auxiliary equipment, spectrum resources (can be an input alternatively) and antennas. Such dimensioning is dependent on coverage and capacity limitations, which are a translation of the input demands to system requirements.

Two dimensioning approaches are taken on this study, a traffic volume based and a throughput based approach considering busy hour. Subscriptions are often priced by a monthly fee in which a data allowance is defined. Also, forecasts often present data growth for users on a monthly bases. On the other hand, throughput is relevant when considering the type of applications that can be served with a given radio access network. Although both traffic metrics can be translated to one another, their intrinsic meanings are relevant *per se*.

The number of subscribers with a given monthly traffic volume a cell can support is given by[9]:

$$N_S = \frac{C_{cell} \times N_{sec}}{8 \times 1024} \times \frac{L_B}{B_{\%}} \times \frac{3600 \times days}{V_S} \tag{2.3}$$

Where C_{cell} is the cell capacity in Mbps given by the allocated bandwidth and the average spectral efficiency, N_{sec} is the number of sectors, L_B is the network load in percentage at busy hour, which is usually assumed less than 100% so that service experience is not degraded, $B_{\%}$ is the busy hour traffic percentage of the daily traffic and V_S it the monthly traffic consumption.

For a throughput based dimensioning, the number of subscribers is obtained by[9]:

$$N_S = C_{cell} \times N_{sec} \times L_B \times \frac{OBF}{r_S} \tag{2.4}$$

Where r_S is the required user bit rate and OBF is the overbooking factor or contention ratio that translates, usually set to 20 by experience, which relates to the cell capacity sharing among several users simultaneously.

The user r_S can be seen as a peak bit rate that translates to an average busy hour bit rate r_A due to cell capacity sharing among cell users, equation 2.5. Moreover, the monthly traffic consumption can be translated to the aforementioned bit rates through equation 2.6.

$$r_S = OBF \times r_A \tag{2.5}$$

$$r_A = \frac{V_S}{3600 \times days} \times B_{\%} \times 8 \times 1024 \tag{2.6}$$

Cost Modeling

The costs, that are input to the analysis, are categorized as CAPEX or OPEX expenditures. CAPEX stands for capital expenditures which are made on tangible assets that can be depreciated over a period of time[10]. On the other hand, OPEX expenditures cover the costs incurred on running and operating a business[11]. On radio access network deployments, CAPEX consists of infrastructure and installation costs while OPEX consider power and operation and maintenance costs and, according to [4], can be evaluated per base station. Both cost categories are affected by price erosion along the period which is due the natural decrease of service and equipment costs.

Spectrum costs are rather difficult to evaluate since not only the investment made through auctions is at stake. Since operators own small portions of spectrum, the value of spectrum is also related to the revenues it might bring in one or another deployed network. However, spectrum costs can be seen as an operational expense[2], an approach taken in this thesis. For the matter, the cost per MHz per population is computed based on PTS auctions results and annualized over the asset life time

[2]Bengt Molleryd, PTS.

providing an EAC[12], equation 2.7.

$$\text{EAC} = \frac{C_{band} \times r_d}{1 - (1 + r_d)^{-P_u}} \tag{2.7}$$

Where C_{band} stands for the cost of the particular spectrum band, r_d represents the discount rate and P_u is the period which the band is owned.

Performance and Cost Analysis

Tho evaluate the scalability performance regarding particular buildings, the architecture of the system required to meet the demands is obtained, more specifically, the network components which perform the main functionality and drive the cost, as base stations and indoor units. Moreover, the required bandwidth is also a factor which requires attention since it may differ depending on the system configuration and is of most relevance for mobile operators when deploying radio access networks.

On the other hand, cost evaluation is done through a TCO computation where both capital and operational expenses are considered so that a comprehensive view of the total cost of owning a system is obtained. Furthermore, it is a fair method to compare alternatives due to the holistic picture provided by the TCO approach[13]. The TCO is computed through a discounted cash flow model where future expenditures are discounted by taking in consideration the cost of money through a discount rate[4], equation 2.8.

$$\text{TCO} = \sum_{i=0}^{T} \frac{CF_i}{(1 + r_d)^i} \tag{2.8}$$

Where i represents the years which span from 0 to T, the system useful life, CF_i is the particular cashflow and r_d the discount rate.

2.3 Qualitative Study

The discussion on single-operator and multi-operator is base on a qualitative study where actors and drives for in-building deployment are explored so that a delimitation of the suitable deployment scenarios for each system are found. Moreover, the effect of spectrum availability and impact of spectrum access method on the possible change of perspective on those deployment options are objective of research.

The data collection was done through academic and industry literature sources and guidelines for deployment scenarios. Furthermore, interviews to network vendors, mobile operators and academics were conducted, in particular:

- Par Tjernström, VP Sales, CommScope
- Tord Sjölund, VP sales, Mic Nordic
- Carlos Caseiro, Vodafone Portugal
- Nelson Lourenço, Vodafone Portugal
- António Lages, Portugal Telecom
- João Romão, Portugal Telecom
- Amirhossein Ghanbari, Researcher, Wireless@KTH

The objective of the conducted interviews was to gather a perspective of both DAS vendors and mobile operators on the issues of indoor coverage in general and regarding the drives and deployment options for multi-operator and single-operator systems.

Chapter 3

Ericsson Radio Dot System

The focus of this thesis is on Ericsson Radio Dot System, particularly on its scalability characteristics and limitations. This chapter introduces the system and also provides the results of an evaluation of coverage and capacity abilities based on system specifications. It can be seen as a first approach towards a comprehensive scalability analysis that will be further developed in the following chapters in an effort to gain insight into the first research question *How are coverage and capacity related for Ericsson Radio Dot System regarding an enterprise scenario?*.

Ericsson Radio Dot System is an indoor cellular network that aims at providing coverage and capacity of WCDMA and LTE technologies in scenarios such as enterprise buildings and public venues. It is expected, in the near future, that traffic volumes and throughput demands will growth in such environments due to the increase of heavy mobile broadband users. Although different systems are already available on the market, which fall either on DAS or femtocells concepts, Ericsson aims at fulfilling a market gap on capacity provision for medium to large buildings, figure 3.1.

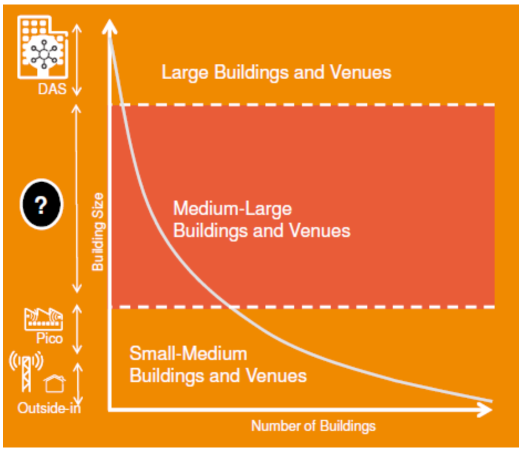


Figure 3.1: Available network solutions for various indoor settings.[1]

The factors that play a major role on indoor network design are building size, which is closely related to the coverage area and the number of users accessing the network, and the user's data volume consumption, which relates to the subscribers' usage of diversified mobile applications with different network demands. On the other hand, the amount of investment network providers are willing to make on such systems is rather dependent on the revenue and benefits the network will provide, see chapter 5 for a discussion on the matter.

The proposition of Ericsson is to provide a solution that meets demand and enables high return of investment (ROI) to *"lower the threshold to building indoor coverage"*[2], particularly within a grey area - large to medium buildings (red area on figure 3.1) - where it is not clear if either smallcells or distributed antenna systems prove to meet both capacity and cost requirements. In fact, DAS have been deployed to provide coverage in large buildings and, due to their partly passive components, an upgrade on network capacity will require a significant investment. On the other side, macro outside-in coverage and smallcells address the residential and smaller office buildings. Dot antenna is the system feature which Ericsson most proudly advertise as a compact and lightweight antenna, with around 300g, which allows a discrete presence indoors, addressing directly the concern of infrastructure owners on antenna visibility and impact on rooms they are placed in. Moreover, modularity is another feature Ericsson emphasizes, figure 3.2a, since it allows dot disks to be interchangeable to enable different bands and radio access technologies.

Ericsson guaranties that Radio Dot System provides seamless service and coordination with Ericsson's outdoor radio networks and carrier WiFi solutions, with support for their real-time traffic steering capability to enhance user experience across 3GPP and WiFi standards. Moreover, several LTE features are also supported as carrier aggregation, combined cell, interference management, Coordinated Multi-Point (CoMP) transmission and reception, traffic management, evolved Multimedia Broadcast Multicast Service (eMBMS), Voice over LTE (VoLTE) and HD voice.

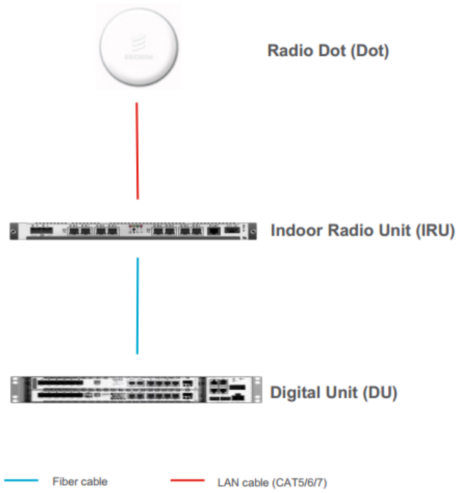
Radio Dot System has been announced on September 2013 and Ericsson claims that it will be commercialized by the last trimester of 2014. Meanwhile several operators have already partnered with Ericsson to trial Radio Dot System, such as MTN, Swisscom, Softbank, SingTel, Vodafone and Telstra. These trials will incise on enterprise buildings and public venues for LTE and WCDMA service provision. AT&T also reacted positively to Radio Dot System announcement: *"A solution like the Ericsson Radio Dot System gives AT&T another tool to choose from in its next-generation toolkit."*[3]

[1]Ericsson.
[2]Johan Wibergh, head of Ericsson Business Unit Networks.
[3]Kris Rinne, Senior Vice President, Network and Product Planning, AT&T Services, Inc.

3.1 Architecture

The Radio Dot System architecture resembles an active DAS since optical fiber is used to connect the head end unit (digital unit) to the remote unit (indoor radio unit) and uses LAN cables (CAT 5/6/7) to link the remote unit to the antennas, figure 3.2b [14]. With such an architecture, that makes use of active components and lowers attenuation within cabling, Ericsson Radio Dot uplink performance is enhanced when compared to hybrid fiber-coax and passive DAS. It results on lower path loss for uplink signal, which enables high uplink bit rates and mobile battery savings. However, contrary to femtocells, dedicated cabling infrastructure is required which increases installation costs and deployment period significantly, see chapter 4 for a cost comparison.

(a) Dot antenna.



(b) Architecture.

Figure 3.2: Ericsson Radio Dot System.[4]

The DU and IRU components allow a deployment flexibility, as seen in figure 3.3, whivh address a multitude of scenarios as medium, large and very large office buildings and public venues as campus, shopping centers and stadiums. The DU offers particular flexibility on efficiently managing capacity by offering the possibility to share the baseband resources with other buildings through IRU distribution or with roof top antennas for outdoors coverage.

The topology, meaning the configuration of components' connections, has a significant impact on system scalability regarding the area and users covered. Radio Dot System is deployed in a star configuration, figure 3.4a, however, cascading, figure 3.5 is also an option.

[4]Source: Ericsson.

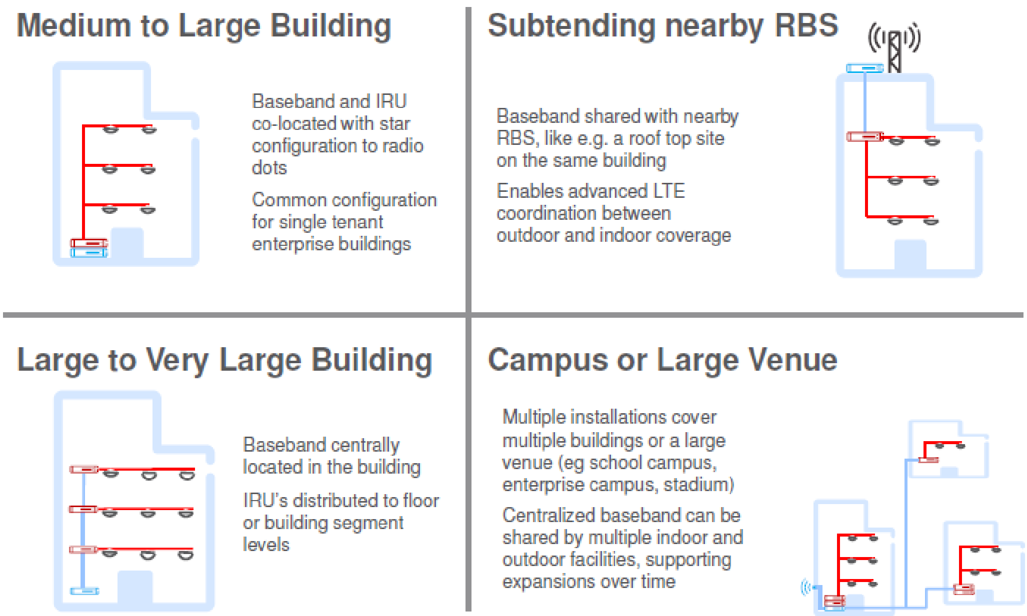
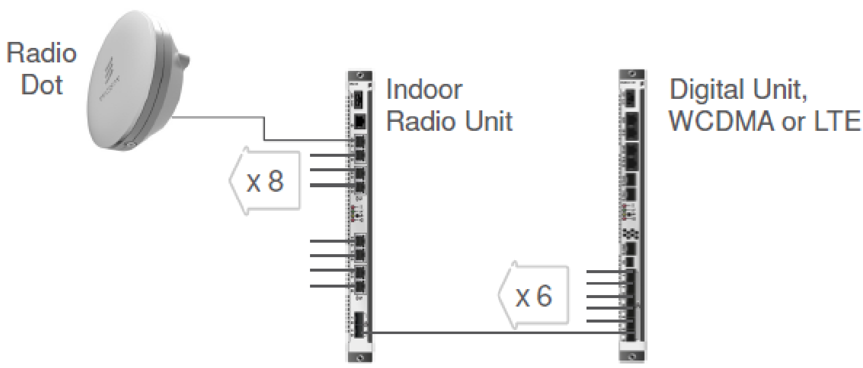


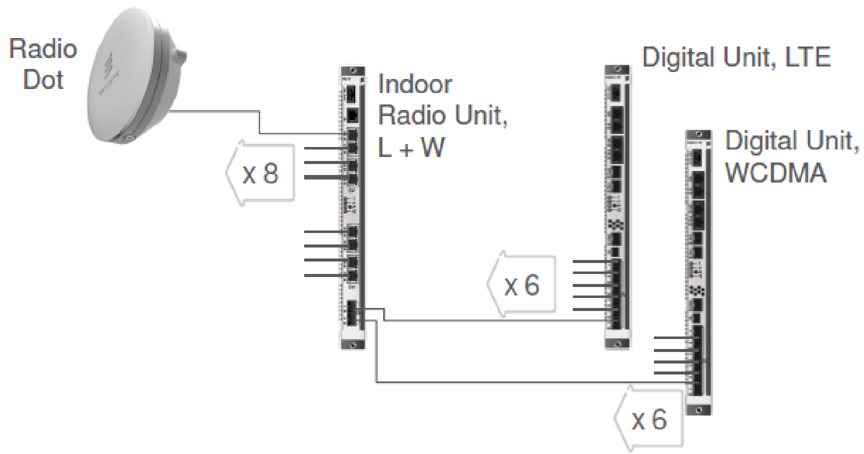
Figure 3.3: Flexible configurations.[4]

3.2 Coverage

Each Dot can cover a squared area of 400 to 900 sqm, depending on the inter-antenna distance, which is limited within 20 to 30 meters, with 25 meters being the recommendation. Up to 8 dots are supported by each IRU, which translates to an IRU coverage up to 7200 square meters. In figure 3.6a can be seen the cell coverage area in function on the number of dots per IRU.



(a) Single mode.



(b) Mixed mode.

Figure 3.4: Star configuration.[4]

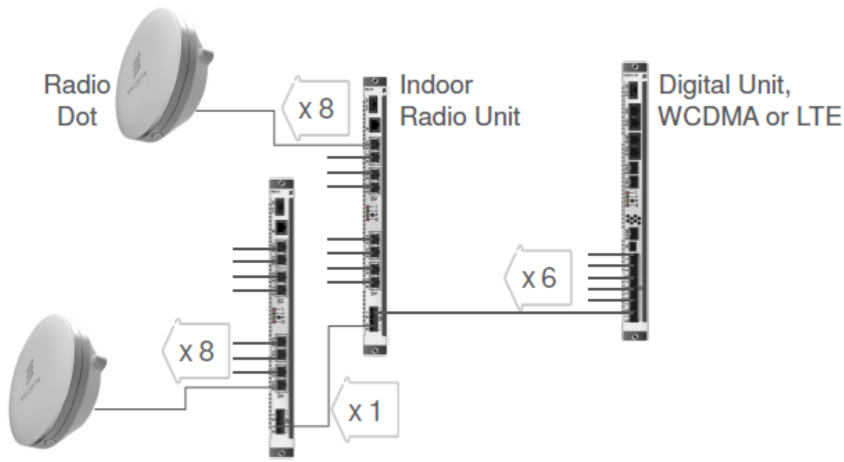
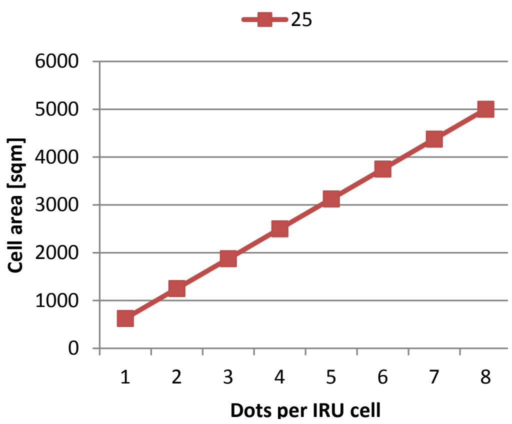
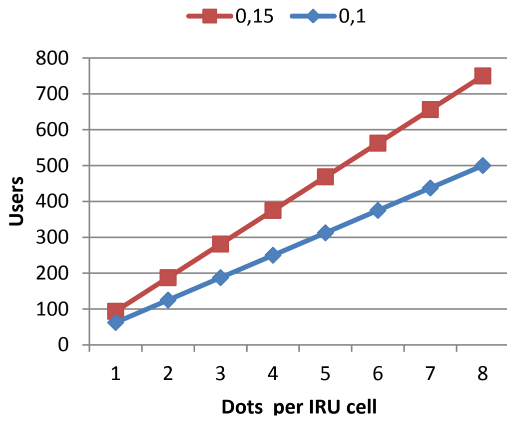


Figure 3.5: Cascading.[4]

The number of users per cell affects network dimensioning and, within an enterprise environment, it is expected an user density around 0,1 to 0,15 users per sqm, see section 4.1. In figure 3.6b can be seen the number of users varying from 63 to 750 users that must be supported within an IRU coverage area, for increasing number of dots connected to the IRU. The significant difference on users within a cell for different user densities shows how this factor plays a significant role on the level of sharing cell capacity. It should be noted that as more users are supported per IRU, there is an higher level of sharing of capacity resources. Both the cell area and the amount of users supported are much higher than for enterprise femtocells, which coverage area is around 315 square meters and 32 supported users.



(a) Variation of Cell area with the number of Dots per cell for 25 meters of inter-antenna distance.



(b) Users per cell for 0, 15 and 0, 1 user density (per sqm).

Figure 3.6: Cell area and users for Radio Dot System.

On a star configuration, figure 3.4a, a maximum of 48 dots is supported by 6 IRUs and a single DU allowing a coverage area up to about 4000 square meters. With this configuration, it is possible to provide both LTE and WCDMA service through mixed mode as depicted on figure 3.4b. Each IRU can support another IRU on a cascading configuration such that up to 98 dots are supported, enabling a coverage area up to about 8000 square meters, figure 3.7 shows the coverage area with 25 meters antenna inter-distance. However mixed mode is not supported with IRU cascading configuration, only LTE or WCDMA is supported.

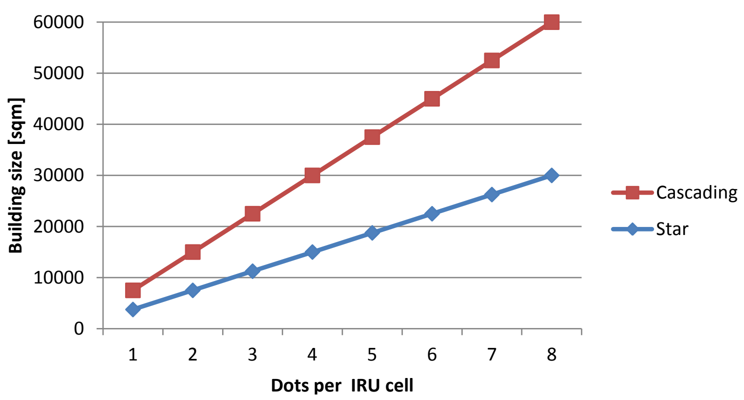
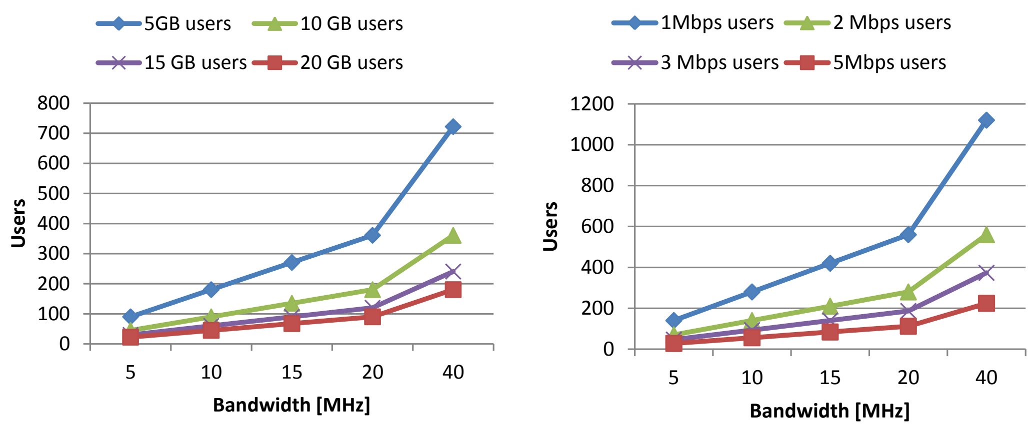


Figure 3.7: Coverage limits for star and cascading configurations with 25 meters of inter-antenna distance.

3.3 Capacity

In this context, capacity is seen as the throughput a cell provides, which translates to the bit rates achieved by a number of users within the coverage area. Each IRU polls the capacity provided by the DU which is further distributed over radio environment by dot antennas, the IRU sectors are seen as cells. In this section it is explored how many users can Ericsson Radio Dot System serve with particular bit rates with variable amount of spectrum resources. Throughout this section it is assumed a spectral efficiency of 2 Mbps per Hz, which is in line with an expected spectral efficiency average with an inter-antenna distance of 25 meters. The spectral efficiency is known to vary between 1,6 to 3 Mbps per Hz within a Dot coverage area. Also, it is assumed a contention ratio of 20:1, a busy hour average loading of 70% and a busy hour to hold 15% of the daily traffic.

For cellular systems, a larger bandwidth allows more served users or, for the same number of users, higher bit rates. Such behavior for Radio Dot System can be seen on figure 3.8, where it is shown the number of users with specific bit rates and monthly traffic volume consumption levels that can be served by one IRU cell for varying bandwidths. However, by comparing with figure 3.6b, a quantified conclusion can be draw: for large cells, with more than 600 subscribers, a bandwidth of 20 or 40 MHz must be used to ensure minimum service requirements as 1 Mbps and 5 GB per month. On the other hand, for the same amount of bandwidth, if smaller cells are used, supporting less than about 200 users, then it is possible to serve all users with 5Mbps and 20GB per month, respectively.



(a) Users served per cell with different monthly traffic volume.

(b) Users served per cell with different peak throughput.

Figure 3.8: Users per cell for different requirements and bandwidth for Radio Dot System.

It is relevant to compare those values with femtocell capabilities. In fact a 16 user femtocell enables a service of roughly a traffic volume of 56 GB per month and a peak bit rate of 17,5 Mbps while a 32 user femtocell provides 8,75 Mbps and about 28 GB per month respectively. It was assumed a spectral efficiency of 4 bits per Hz and a bandwidth of 5 MHz. Those bit rates are rather high if compared, for example, with HD video streaming which requires a bit rate of 5 Mbps. The fact that femtocells allow less users than Radio Dot System per cell, enables higher bit rates for the same amount of bandwidth. However, femtocells capacity exceeds the demand in most scenarios, as shown by the computed values above, which makes it prone to high levels of overprovisioning. Moreover, the major limitation is coverage which, due its low range, require a deployment of high number of base stations for large buildings as enterprise ones.

In conclusion, Radio Dot System enables extended coverage more easily than femtocells but these enable higher system capacity due to smaller cells and higher frequency reuse. However, Ericsson Radio Dot System resembles a femtocell cell size deployment when only one dot is connected to the IRUs. In that case, due to lower spectral efficiency, the system provides lower peak throughput than femtocells but can support higher user densities since the simultaneous connections are not as limited as in femtocells' case. Another factor playing a significant role is operational and deployment cost of both solutions, which will allow a comparison regarding additional parameters as, for example, the impact of the different amount of allocated bandwidth, see section 4.4 and 4.4.

3.4 Capacity and Coverage Trade-off

Cell coverage and capacity were addressed on the previous sections, however, their interplay for the entire system was not explored, it is the matter of this section. It was seen that bigger cells allow an increased coverage area while smaller cells enable higher bit rates, there is a trade-off between the covered area and the bit rates provided. In figure 3.7 that trade-off is identifiable, different bit rates are displayed for varying coverage areas, represented on the xx axis, and for varying user densities, represented on the yy axis. Although it might seem beneficial from a coverage point of view to have bigger cells, the increase of cell area translates to more users to be supported, which means that the capacity of the cell will be shared among more users. Moreover, higher user densities also translates to more users within a cell which requires more capacity sharing and lower achievable bit rates for the same cell throughput.

The coverage area and provided capacity also depends on if star (mixed mode) or cascading is used, with the implication whether both LTE and WCDMA are enabled. The bottom xx axis on figure 3.7 shows the achievable coverage area for

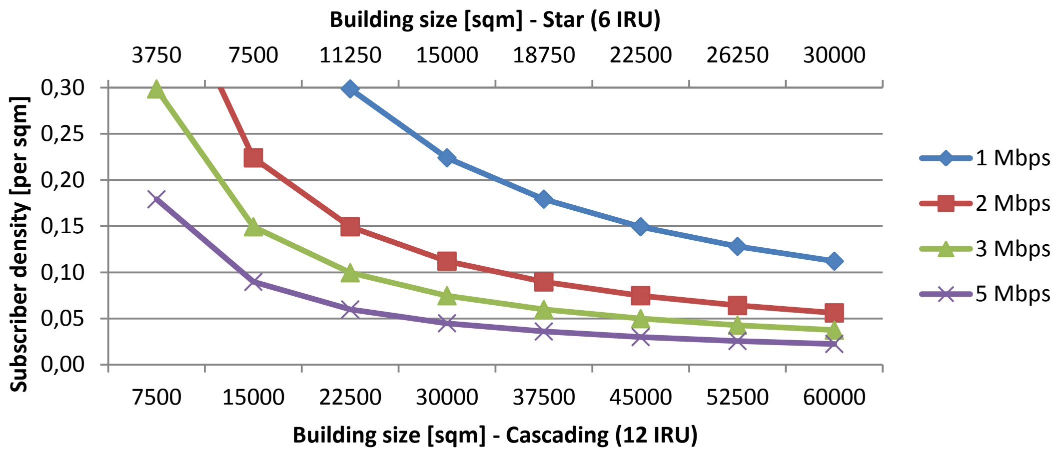


Figure 3.9: Peak throughput on the busy hour in function of user density and cell size, assuming 20 MHz of bandwidth.

specific bit rates, under a particular user density, when cascading is used (a total of 12 IRUs are deployed). The upper xx axis represents the same but for star topology (a total of 6 IRUs are deployed). With cascading is possible to cover bigger areas or for the same area covered by star, provide higher bit rates (due to use of smaller cells and higher sectorization by doubling the number of IRUs).

It is assumed that only one DU is used for a building, however, it is possible to have more than one DU and therefore increase the number of IRUs. If there is no limit for the number of DUs, a configuration of one dot per IRU would provide the smallest cells and enable high user bit rates. However, from a cost and deployment point of view it might not be beneficial.

If, instead of 20 MHz, 40 MHz of bandwidth are available, higher user bit rates are reachable. By doubling the bandwidth, the system throughput also doubles. However, it is not clear that operators are willing to dedicate or even share such amount of spectrum to an indoor solution.

Chapter 4

Scalability analysis

The previous chapter focused on coverage and capacity limits of Ericsson Radio Dot System and general insights regarding achievable service levels were gathered. However, it is interesting to look at realistic scenarios with buildings of different dimensions and user densities to get a picture of which service levels are expected to be provided by Radio Dot System. That is the purpose of this chapter where, using the results form the previous chapter, will be seen for different enterprise buildings what service levels are achievable and with which configurations. The focus of the analysis is on enterprise scenarios since those are one of the targets of Radio Dot System, figure 3.1. Moreover, enterprise buildings are the major scenario for which mobile operators are willing to deploy single-operator systems.[1]

The analysis developed in this chapter is a direct contribution to the research question: *How are coverage and capacity related for Ericsson Radio Dot System regarding an enterprise scenario?* by narrowing down the analysis of the previous chapter to particular configurations on realistic settings. Moreover, it is conducted a second study to understand how can Radio Dot System provide a future proof solution to cope with the traffic and capacity demands yet to come. For the purpose, a traffic demand between 2014 and 2026 is modeled to evaluate which is the road map Radio Dot System provides to meet coverage and capacity for two particular enterprise buildings.

4.1 Enterprise scenarios

To get realistic values for enterprise building parameters, several buildings of an evolving business district, Kista (Sweden) were used to model the office area and user density. The buildings were chosen such that the differences in size and users are significant, table 4.1. The information was collected from building plants

[1] Interview with Vodafone Portugal.

and, for the purposes of this study, it is assumed that the workspaces are a fair representation of the number of workers inside the building at busy hour.

Building	Victoria Tower	Kista Inside	Hornafjord	Scadinavian BB	Kista One
Office Area [sqm]	4938	11668	9000	28540	34678
Workspaces	695	1061	1313	2912	3004
User Density [person per sqm]	0,14	0,09	0,15	0,10	0,09

Table 4.1: Enterprise buildings chosen from Kista Science City.

The buildings depicted on table 4.1 can be categorized on medium to large buildings, where Victoria Tower would be considered medium size whereas Kista One would be a large building. These buildings fit on the targeted scenarios of Ericsson Radio Dot System as their office area is within system coverage limits. On the other hand, the user densities do not vary significantly since it is quite characteristic of enterprise offices. Nevertheless, the small difference will still allow a perception of its impact.

By enterprise building it is meant that indoor space is owned or rent by companies and it is where workers develop their activities during office hours. In fact, enterprise traffic has patterns associated with these activities and has rather different cycles than residential areas, figure 4.1. It is assumed that all enterprise traffic occurs within 8 office hours and 22 working days.

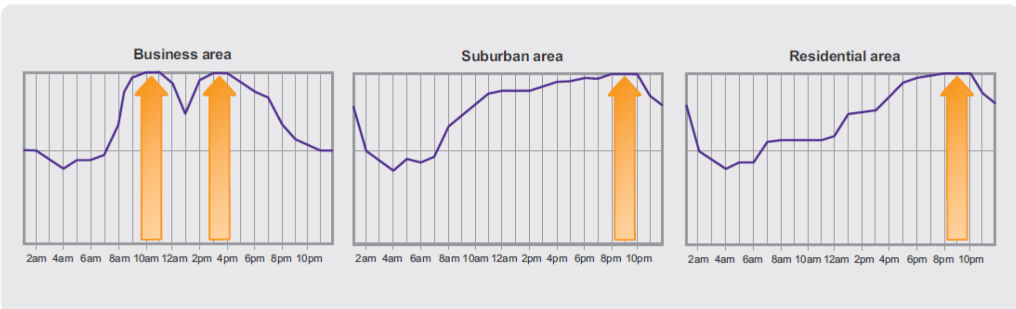


Figure 4.1: Daily traffic for different areas.[2]

[2]Liquid Radio, Let traffic waves flow most efficiently, White Paper, Nokia Siemens Networks

4.2 First Scenario: providing video streaming bit rates

From the scenarios presented by Ericsson, figure 3.3, the idea is that one DU is deployed per building or even per campus. However, this assumption depends on the buildings size and the traffic demands. This section aims at understanding when one DU is not enough to provide the capacity required. For the matter, a network dimensioning is made for the enterprise buildings presented on the previous section. The dimensioning aims at the system being able to provide enough capacity for various user video streaming bit rates. It is assumed that one LTE carrier, 2×20 MHz, is available for indoor coverage.

In figure 4.2, it is shown different bit rates for different video qualities, the difference between video quality for mobile and high definition is significant. As a LTE system, Radio Dot System should be able to provide 4G quality and, to compete with WiFi, it should also enable enough throughput to achieve higher video qualities.

Application	Bit Rate [Mbps]
HD 1080p @ H.264 high profile	5
HD 720p @ H.264 high profile	2,5
LD 360p 4G Mobile @ H.264 main profile	0,7
LD 240p 3G Mobile @ H.264 baseline profile	0,35

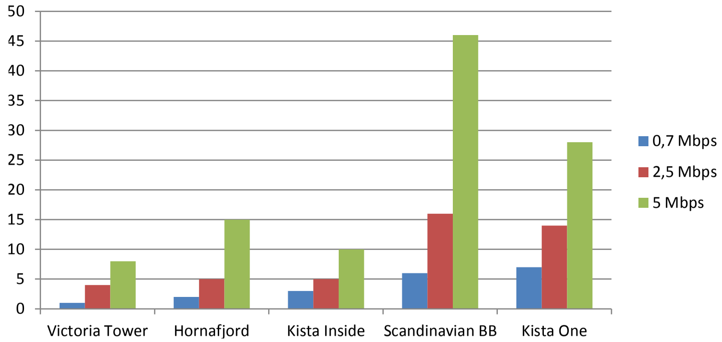
Figure 4.2: Bit rates for different video qualities.

When is one DU not enough?

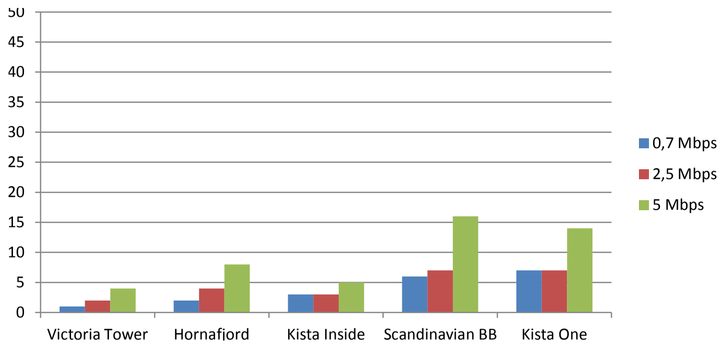
Figures 4.3a and 4.4a show the number of IRUs and DUs required to provide enough capacity to ensure the aforementioned video streaming bit rates. For the small building, Victoria Tower, one DU is enough to provide even the highest bit rates.

For medium buildings, Hornafjord and Kista Inside, one DU can support up to HD 720p video quality bit rate (2,5 Mbps). However, for the highest quality (HD 1080p, 5 Mbps) the need for more than one DU depends on the number of users per sqm. That is why Hornafjord, in spite being a smaller building has more users, requires two DUs to ensure the 5 Mbps. Both LTE and WCDMA, which are not supported with more than 6 IRUs, can be provided in small and medium buildings where the user bit rates are up to 2,5 Mbps.

On the other hand, one DU can only support the 4G video bit rate for larger buildings as Scandinavian Business Building and Kista One. To provide HD 720p video, two DUs are required for both buildings and three and four DUs for Kista One and Scandinavian BB, respectively, to ensure HD 1080p video bit rate.

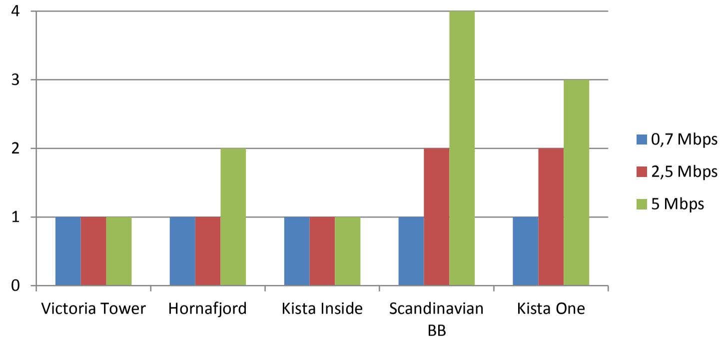


(a) With 20 MHz.

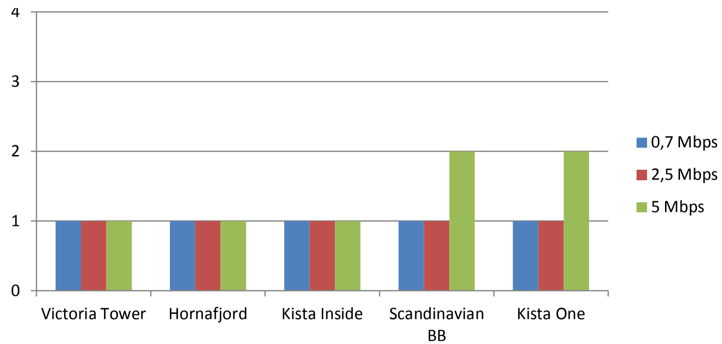


(b) With 20 MHz and cell splitting.

Figure 4.3: Number of IRUs to meet throughput demand for video streaming.



(a) With 20 MHz.



(b) With 20 MHz and cell splitting.

Figure 4.4: Number of DUs to meet throughput demand for video streaming.

Providing capacity for larger buildings

The fact that to provide higher user bit rates it is required smaller cells, or IRU sectors, the limitation on supported IRUs per DU drives the need for more DUs when the coverage area is large. On the other hand, if more capacity is available at each cell, the cell size does not need to be as small and the DU limits may not be pushed. That could be done through the use of larger bandwidths, as 40 MHz (two LTE carriers) which would roughly double the capacity, or by increasing spectral efficiency through radio management and planning techniques. However, two LTE carriers often used in the macro layer where coverage area may reach several kilometers and it is not clear if mobile operators are willing to allocate as much spectrum as 40 MHz for indoor solutions. If spectrum shared access methods take of, maybe such high bandwidths would be achievable at reasonable costs.

Another alternative is to enable cell splitting, in that case, each IRU would provide two cells instead of one. If cell splitting is considered, as in figures 4.3b and 4.4b, then it can be seen that the number of components decrease considerably. Furthermore, one DU can provide for 2,5 Mbps for small to large buildings and 5 Mbps for small to medium buildings. To provide 5 Mbps for large buildings, a decrease from four and three to two DUs is seen. With cell splitting it is possible to have less network components which will impact the cost-efficiency of the system, more on the section 4.4.

4.3 Second Scenario: road map to meet evolving traffic demands

The traffic volume, in particular in cellular networks, has been growing exponentially and the trend is set to continue. The consequence is that mobile operators' networks will be flooded with data traffic, the so called data "tsunami". Operators are interested in solutions that are able to cope with such demands on a cost-efficient manner. In this context, it is relevant to see how Ericsson Radio Dot can meet such requirements since Ericsson has been marketing the system as a tool to cope with such network load by providing capacity indoors and offloading the macro network. In this section, such proposition is evaluated for two buildings, Kista Inside and Kista One, with the same user density but different size. The demand is evaluated for the period between 2014 to 2026, a 12 year period. For the matter, the demand for mobile broadband by enterprise users is modeled according to the forecasts presented on section 2.2. Furthermore, the analysis is conducted for various bandwidth allocations which was not presented so far in this thesis.

The major reason for the long period evaluation is that system limits are being pursued, however, the time interval is divided on shorter periods that can be analyzed *per se*, being 2014 to 2018, 2018 to 2024 and 2024 to 2026. Cisco forecasts predict monthly mobile broadband comsumption for enterprise users to grow at a CAGR of 25% during the period 2013 to 2018. However, as discussed on section 1.1, such traffic rate growth is expected to naturally decline over the years and, for the purposes of this study, it is modeled with a lower CAGR of 5% for the periods 2018 to 2024 and 2024 to 2026. Such growth rates are dependent on the capacity enabled by mobile networks and, for example, if a shift from an WiFi based usage to cellular will occur.

Traffic forecast

According to PTS, an enterprise user consumed a traffic volume of 3,8 GB per month on Q1 2013, considering both cellular enabled devices and dongles. Cisco provides an estimation of 7 GB per month when considering the traffic generated by a 4G smarthphone, a 4G tablet and a laptop for an average user. By taking into account that the traffic an user generates within enterprise premises is about 47% of the traffic generated by an average user (PTS), a similar estimation is achieved. In figure 4.5 can be seen the evolution of the monthly traffic volume generated by an enterprise user with a 4G smartphone, 4G tablet and a laptop.

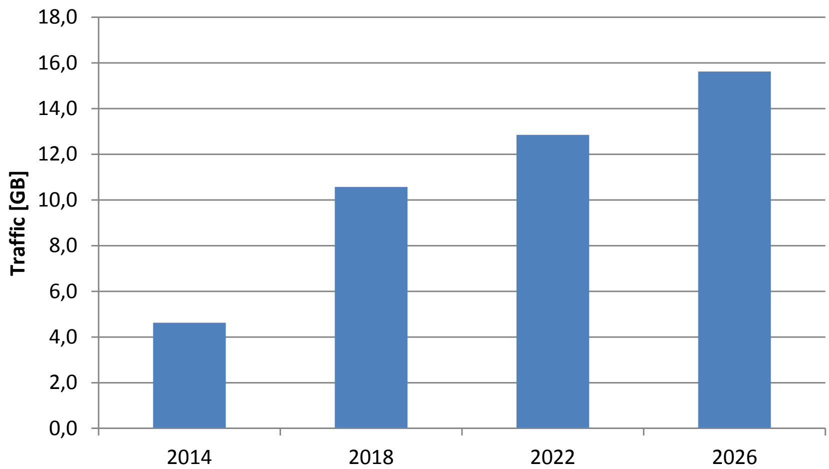


Figure 4.5: Monthly traffic volume evolution for an enterprise user.

For network dimensioning, it is used the approach discussed on section 2.2 based on the capacity required at busy hour, where $B_{\%}$ denotes the percentage of the daily traffic that occurs within the busiest hour of the day. According to Cisco, the busiest hour carried about 66% more traffic than an average hour, which translates to 19% of the daily traffic. However, as traffic increases, the percentage of traffic carried on the busy hour also increases and, according to Cisco, the busy hour traffic will increase 5% in comparison to the average hour. In figure 4.6 is represented the expected evolution of the the busy hour traffic percentage.

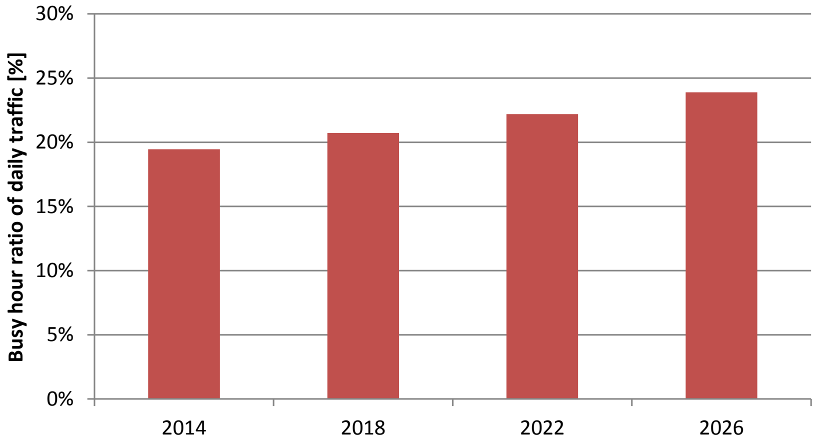


Figure 4.6: Evolution of the traffic carried on the busiest hour as a percentage of daily traffic.

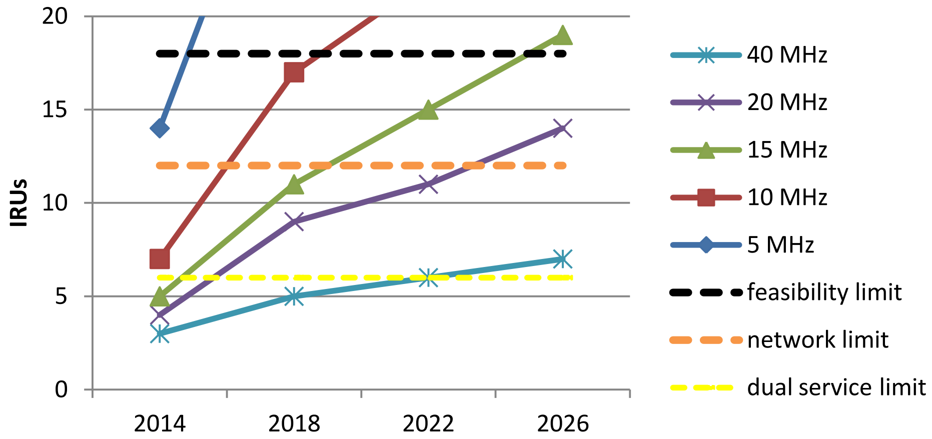
Road map to meet future demands

In figure 4.7 is shown the number of IRUs required to meet the demands, within the considered period, for different amounts of allocated bandwidth. Moreover, three limits are defined:

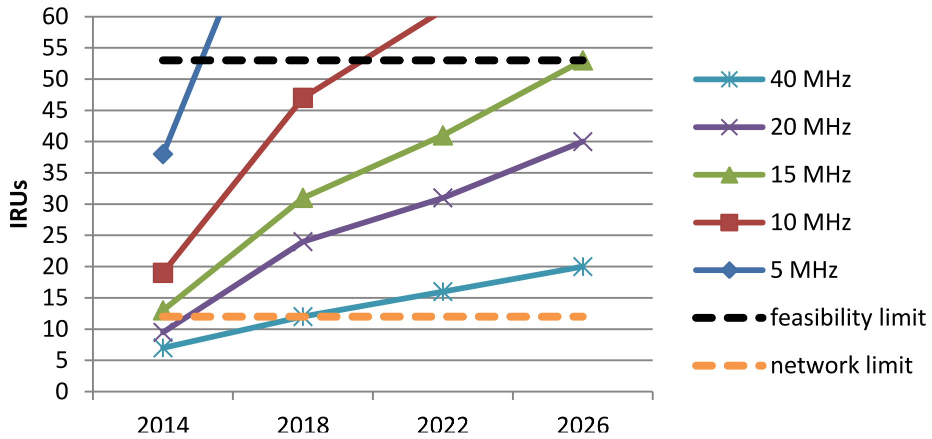
- **Dual service limit** defines the maximum number of IRUs that enables the system to provide both WCDMA and LTE;
- **Network limit** defines the frontier on the amount of deployed IRUs that require more than one DU to be deployed;
- **Feasibility limit** delimits the maximum number of IRUs that can be deployed in the building, it corresponds to the scenario where only one DOT is connected to one IRU.

A trade-off between spectrum and number of IRUs is the most relevant result shown on figure 4.7. Moreover, the limits defined above impose limitations to that trade-off. For example, for Kista One it is not possible to provide both services due to coverage constrains, therefore the dual service limit is not shown. The provision of both WCDMA and LTE within Kista Inside is possible provided that the bandwidths required are available, 15 MHz for 2014 and 40 MHz for 2018 forward.

The gap between the feasibility and network limits represents a system that requires more than one DU, its height depends on the building size. In fact, it can be seen from figures 4.7a and 4.7b that it is proportional to the building size ratio, around 3 for Hornafjord and Kista One example. Furthermore, the network limitation is quite small which does not allow a Radio Dot System deployment on Kista ONE to meet traffic demands after 2018 with one DU, even with 40 MHz available.



(a) For Kista Inside.



(b) For Kista ONE.

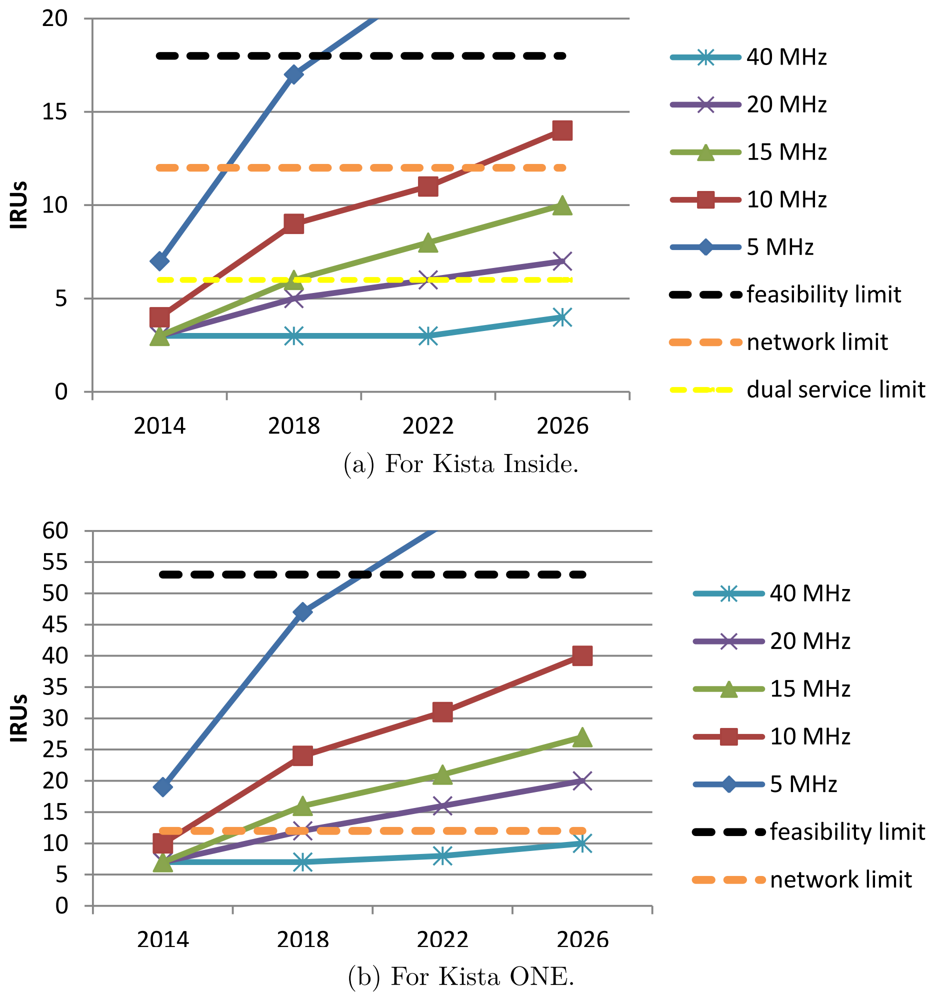
Figure 4.7: Number or IRUs required to meed demands for Kista ONE for different bandwidth allocations.

The two buildings analyzed differ on size and since the network limit is the same, it can be seen that it puts more strain on the required bandwidth as the building size increases. Furthermore, as the demand increases, two options are available: to increase the available bandwidth or to increase the number of IRUs. For bigger buildings, those options are not enough to meet future demands.

Providing capacity for the future

The previous analysis pointed to the need of alternatives to wider bandwidths and more IRUs. One solution is the deployment of more than one DU which would support more IRUs. However, this would increase system complexity and cost by leading to an scenario with less Dots connected to each IRU with the limit being the feasibility limit. In fact, the area between the feasibility and network limits can be taken advantage off by adding more and more DUs.

The limitation of the maximum number of DUs is not clear and an high number of those components would likely increase cost and lose advantage to other indoor capacity alternatives, see section 4.4. On the other hand, an alternative could arise by a multicell scenario where each IRU would provide more than one cell. For the



(a) For Kista Inside.

(b) For Kista ONE.

Figure 4.8: Number of IRUs required to meet demands for different bandwidth allocations considering cell splitting.

case of each IRU supporting two cells, named cell splitting, it is seen in figure 4.8 the shape of the same spectrum and number of IRUs trade off.

The most relevant change is that it is possible to meet future demands for Kista ONE with cell splitting. Moreover, for Kista Inside the strain in spectrum is also lessen and it is possible to use smaller bandwidths or less IRU components. If an further cell division is accomplished, the network limit would loosen even more and capacity could be provided with less spectrum and bandwidth for bigger buildings. However, improved radio resource and control techniques would be required for better interference and handover management.

4.4 Cost Analysis

In this section a study on the cost of deploying Radio Dot System is conducted to provide input to the second research question: *How does Ericsson Radio Dot System cost compares with femtocell and macrocell networks on an enterprise setting?* The study comprises a TCO analysis[3], as described on chapter 2.2 related to the both scenarios of the previous section and an qualitative evaluation of spectrum value. Furthermore, a comparison is made with a femtocell and a macrocell deployment for the same traffic volume levels.

For the TCO analysis, the period consider has a timespan of 8 years ($T = 8$), extending from 2014 (year 0) to 2026 (year 8). The cost of capital and price erosion are assumed as 7,8% and 5% respectively. It is considered that Dots and IRUs have a useful life of 4 years while DUs have 8 years, as such, replacement is considered throughout the system period.

Cost Evaluation for First Scenario: providing video streaming bit rates

As an extension of the study conducted on 4.2, it is of interest to evaluate the cost proportions of providing video streaming bit rates. For the matter, a TCO analysis is taken where is considered a service provision of 2.5 Mbit/s user bit rate during a period of 8 years, the results of section 4.2 are used for dimensioning.

How does cost relate for the different options?

In figure 4.9 can be seen the TCO of Radio Dot System, deployment of femtocells and coverage by outdoor macro. The assumptions regarding the cost structure can be found on appendix A. It is assumed a capacity of 32 users per femtocell and a spectral efficiency of 1,67 bit/Hz for macro outside-in coverage, for the assumptions on spectrum refer to section 4.4.

[3]The cost of Radio Dot System components was based on a DAS System since no data is available yet.

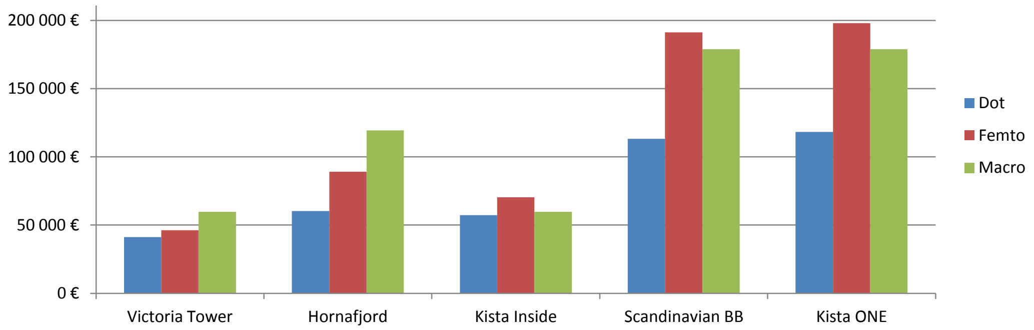


Figure 4.9: Evolution of the traffic carried on the busiest hour as a percentage of daily traffic.

According to the assumptions made, it can be seen from the results of figure 4.9 that Radio Dot System is the most cost efficient solution, under a TCO perspective, for all buildings under analysis. The difference in cost proportions is higher for Hornafjord, Scandinavian BB and Kista ONE which indicates that Radio Dot System has an increased cost advantage against femtocells and macro coverage for higher user densities and bigger buildings.

For Victoria Tower and Kista Inside, the cost advantage of Radio Dot System over femtocells and macro coverage is not as significant. To understand how can the difference in cost can be accentuated, it is relevant to look at the cost in terms of CAPEX and OPEX of Radio Dot System. In figure 4.10 is represented the equivalent annual CAPEX and OPEX components of the TCO shown on figure 4.9.

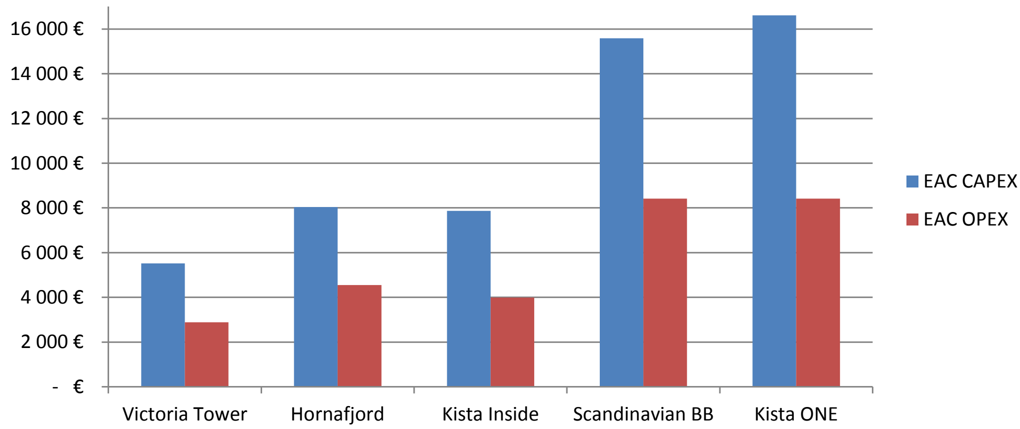


Figure 4.10: Evolution of the traffic carried on the busiest hour as a percentage of daily traffic.

As shown in figure 4.10 the CAPEX component dominates the cost structure for all buildings. As such, a reduction on the cost elements of CAPEX will provide an higher effect on TCO advantage over femtocells and macro coverage, see appendix A for the CAPEX elements assumed and the cost structure.

Cost Evaluation for Second Scenario: road map to meet evolving traffic demands

In the previous section was identified the need for differentiation in terms of cost considering smaller buildings and higher user densities. Moreover, in section 4.3 cell splitting was seen as a way to provide more capacity at less spectrum and IRUs expense. This section explores if cell splitting can also be an option to improve the cost advantage of Radio Dot System towards femtocell deployment and macro coverage. For the matter, the dimensioning results of section 4.3 are used regarding Kista Inside building, one of were the cost advantage of Radio Dot System is smaller under the assumptions of the previous section.

Can cell splitting differentiate cost wise?

In figure 4.11 is shown the equivalent annual cost for CAPEX and OPEX components for Kista Inside capacity provision with Radio Dot System when considering cell splitting and not. A reduction in terms of EAC is seen of 17,5% on CAPEX and 16,0% on OPEX, which amounts to 17,1% on TCO. In this case, cell splitting allows a capacity provision with less IRUs which decreases both CAPEX and OPEX due to less equipment capital expenditures and less points of failure.

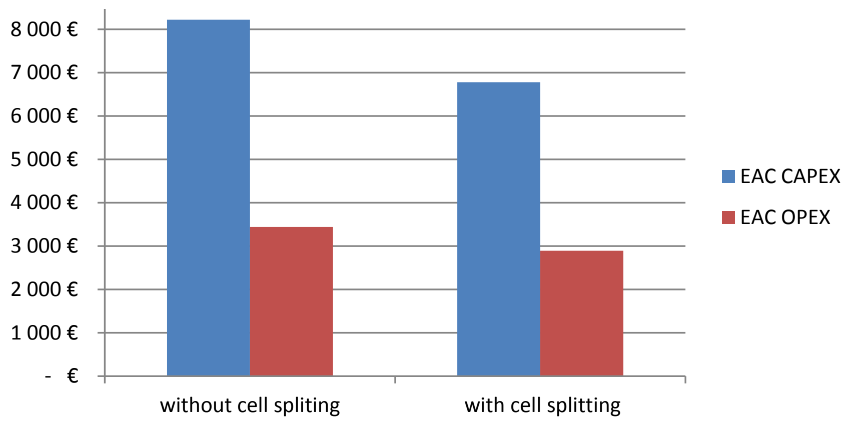


Figure 4.11: Equivalent Annual Cost comparison with and without cell splitting for Kista Inside.

A TCO reduction of around 17% is relevant and would represent a significant cost advantage towards femtocell deployment and macro coverage. Cell spitting is a way to increase Radio Dot System small advantage seen on section 4.4. In figure 4.12 is shown the approximate EAC per person and per sqm when cell splitting is considered and not.

	€/person	€/sqm
without cell splitting	11,57 €	1,05 €
with cell splitting	9,59 €	0,87 €

Figure 4.12: Normalized EAC TCO per person and per sqm with and without cell splitting.

Spectrum Value

In the TCO analysis shown in this chapter, the spectrum resources value were not considered. However, spectrum is a expensive and scarce resource which mobile operators want to get the most return of investment. As such, the amount of bandwidth available for indoor solutions is conditioned and dependent on each mobile operator spectrum strategy. With that on mind, this section provides a qualitative analysis of the spectrum resources required for the dimensioning done in section 4.2.

In figure 4.13 can be seen the relative difference of the spectrum value for the deployment of Radio Dot System, femtocells and macro outside-in coverage for the buildings analyzed on the previous sections. The spectrum value is computed according to an EAC per person and considering the values of the Swedish auction for the 2,6 GHz band occurred in 2008.

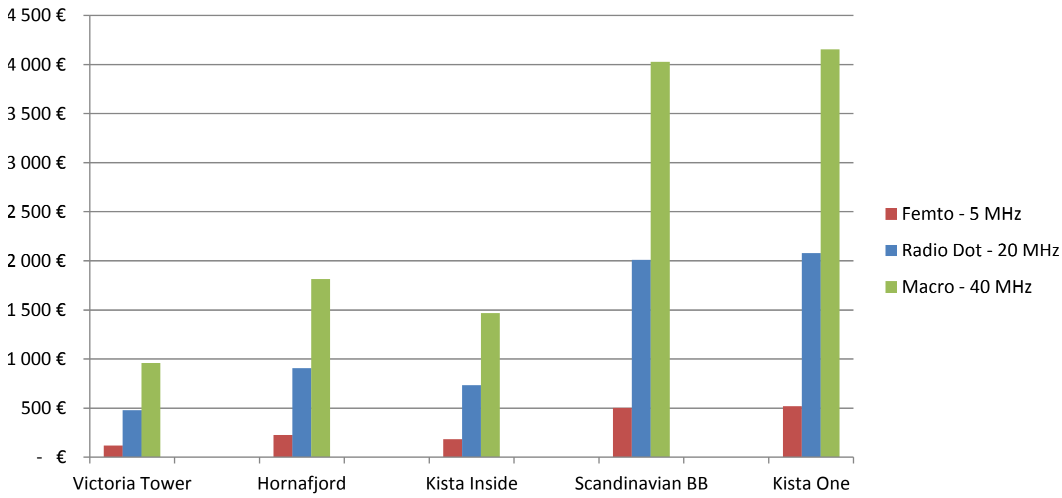


Figure 4.13: Spectrum relative value for indoor capacity provisioning in enterprise buildings.

Femtocells provide a higher spectrum spatial reuse by being a smaller power footprint base station and, as a result, less bandwidth is required for the same capacity provided by Radio Dot System and macro coverage. Also, as seen in section 4.3, there is a trade off between required bandwidth and number of IRUs to provide a certain capacity. In that sense, the spectral cost for a Radio Dot System can be anywere between the spectral values of femtocell and macro layer since it can be compensated by the number of IRUs, which translates to an increased or decreased cell size which in turn effects the spectrum spatial reuse.

As mentioned before, the spectrum strategy differs for each operator and the fact that Radio Dot System can balance the spectrum value with the number of IRUs, thus the CAPEX and OPEX, is an advantage in terms of scalability by comparison to femtocells and macro coverage.

Chapter 5

Multi-operator and Single-operator In-building Networks

To reduce network costs, mobile operators often resort to some form of network sharing on the macro layer which has proven extended reductions on capital expenditures depending on the level of sharing[15][16][17]. The same approach can be extended to in-building networks for femtocells and DAS[18]. In fact, it has been common practice to share DAS infrastructure but that is not the case for small cells[19]. However as femtocells expand its market reach, from residential and small business to larger enterprise buildings and public venues, the need for support of multiple operators and infrastructure sharing is clear[19]. In fact, Cloudberry, the first company to provide ScaS, Small cell as a Service, has recently announced the support of multi-operator functionality through their small cells networks[1]. However, Ericsson with Radio Dot System seams to be moving on the opposite direction, towards single-operator support whereas other companies see the case for multi-operator DAS[2].

One of the decisions involved in in-building coverage deployments is the choice between multi-operator or single-operator systems and what motivates one or other option is most related with business aspects rather than technical issues. In this chapter, insights on the reasoning behind those choices are explored and the deployment models, in which one or other option are pivotal, are identified to answer the third research question: *What are the deployment options for Ericsson Radio Dot System as single operator?*

In in-building deployments several actors can be identified which may play different roles depending on the scenario settings. As such, the actors involved and their requirements for indoor systems are explored with the intend to grasp which

[1] http://cloudberrymobile.com/news/8/23/Cloudberry-Mobile-Launches-Operator-Neutral-Small-Cell-Networks

[2] As Corning.

scenarios multi-operator and single-operator are most suitable. On the other hand, the value proposition both options can bring to each actor contributes to the willingness to invest, which is a measure of the interest on one or other option.

Moreover, spectrum is a resource that has a major impact on any radio access network deployment which in-building are no exception. In fact, it is an even more delicate issue in indoor deployments which will be discussed in this chapter. Furthermore, spectrum access can influence the drives for multi-operator and single-operator in-building networks by defining the strength of the spectrum owner role.

5.1 Who is involved in in-building networks?

Mobile operators, as owners of licensed spectrum, are the entity that provides the frequency resources to in-building networks and, ultimately, who approve if a system can connect to their network. On the other hand, in-building systems are a mechanism to offload hotspot traffic from their macro networks and are a tool to improve service quality which can be a distinguishing factor regarding competitors. However, installing and operating in-building systems is rather complex when comparing to macro networks since the number of nodes is much larger, which requires more support activities and costs may reach higher levels for operation and maintenance.

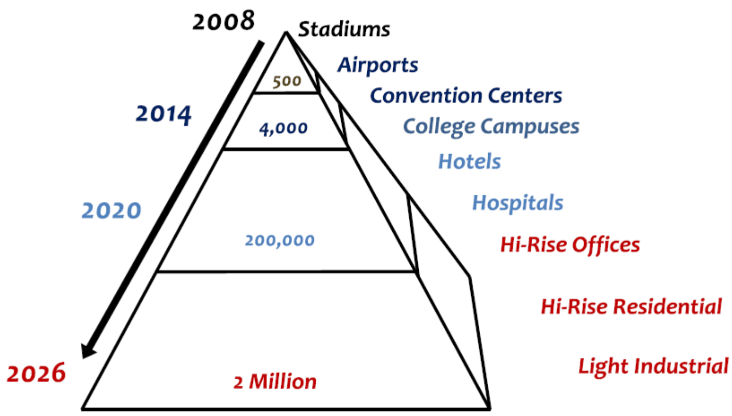


Figure 5.1: The market for in-building networks is growing.[3]

Moreover, the market for in-building solutions began with large buildings with coverage needs or high traffic demands due to high people affluent as airports, stadiums and hospitals, which are not constructed in high numbers. However, as individual traffic consumption rise, particularly data, hotspots are appearing on other

[3]Source: Mobile Experts.

scenarios, as office buildings and residential areas, in increasing numbers which may not be manageable by mobile operators[20], figure 5.1. It introduces a gap that third parties can take advantage of by installing and operating in-building networks as a service for mobile operators or infrastructure owners. Such situation originates business models as ScaS, as Cloudberry, and DAS providers, as American Castle and Crown Castle, with a similar business model to tower providers. However, such local operators do not have the investment means to own licensed spectrum which requires a close relation to mobile operators as spectrum providers[19].

On the other hand, as connectivity becomes the fourth utility, infrastructure owners understand the advantage for their business that coverage and capacity of cellular networks can provide. Voice and seamless connectivity to outdoor networks have been the major driver for in-building cellular systems. However, as mobile applications accustom users to data consumption on cellular networks and WiFi fails to provide the required QoS, higher bit rates and cellular capacity indoors becomes another drive for in-building deployment.

Willingness to Invest

Willingness to invest is related with the benefits brought by the in-building network, either regarding expected revenue or consumer attraction and maintenance. For example, infrastructure owners realize that capacity is not an exclusive obligation of mobile operators as it has been perceived with coverage for previous generations. Moreover, there is an understanding of the burden that the traffic generated on those buildings places on mobile operators macro networks. As such, infrastructure owners are willing to invest in indoor solutions provided that certain service requirements are met, one being the availability of multiple operator services without the installation of multiple networks[19].

Mobile operators are willing to invest in indoor solutions when the revenue expected compensates the investment, which happens when a deal is made with a high revenue costumer or in hotspots where high traffic generation is expected from subscribers.[4] Moreover, it can be a tool to reduce customer churn thus maintaining revenues. On the other hand, in-building solutions can provide a differentiated user experience to steady revenue generation clients, as large enterprise costumers. If, on one hand, operators find an advantage to have full control of their networks, on the other hand, pursue strategies to leverage network costs by network sharing and roaming, which translates to the decision to opt either by a single-operator or a neutral-host solution.

[4] Interview with Vodafone Portugal.

Third parties role on in-building network deployment is to take care of installation and operation processes while making the up front investment. The revenue is generated by fees payed by infrastructure owners and carrier providers which both benefit from the system, to operators as a revenue source and traffic offload and to infrastructure owners by added value to the building.

5.2 Deployment and Financing Scenarios

The discussion lead up to this point has focused on the actors and drives for in-building networks. It provides a build up to deployment scenarios, explored on this section, in the sense that who owns the network has the ultimate decision on the multi-operator or single-operator choice. The drives explored in the previous sections for each party allow to understand the requirements leading to one or other option.

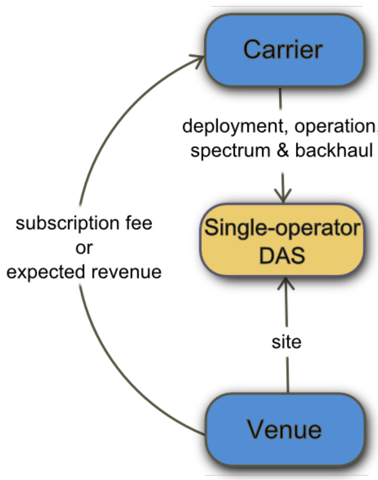


Figure 5.2: Actor configuration when mobile operator owns the network.

Depending on the building and clients at stake, which drive the willingness to pay of the different actors, there are three most common deployment and funding configurations. In some situations, mobile operators are willing to deploy the indoor solution, where they are responsible by installing and operating the network while making the upfront investment, figure 5.2. In such case, the network is owned by the mobile operator and the decisions involved on the system specifications are done by the operator. Operators resort to this option when find a steady revenue stream from the building that will, in long term, return the investment and will likely decide on a single-operator solution. Since building owners do not have much of a decision power in such deployment setting, often they prefer to invest themselves on the indoor network to guarantee that their requirements are met and not defined by the operator, figure 5.3. Moreover, infrastructure owners may choose to deploy a multi-operator solution provided that ensures all operators' requirements. The role of mobile operators is to provide connectivity between the building to the core networks and to provide the spectrum resources.

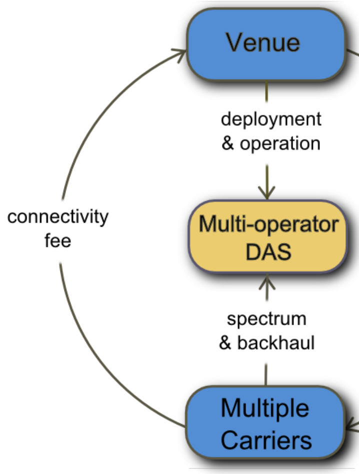


Figure 5.3: Actor configuration when the infrastructure owner owns the network.

On the other hand, third parties or neutral host providers may take the installation and operation activities, acting as an intermediary between the building owner and mobile operators by request of one or other, figure 5.4. Moreover, third parties profit by leasing the indoor system to mobile operators which raises the interest for multi-operator systems.

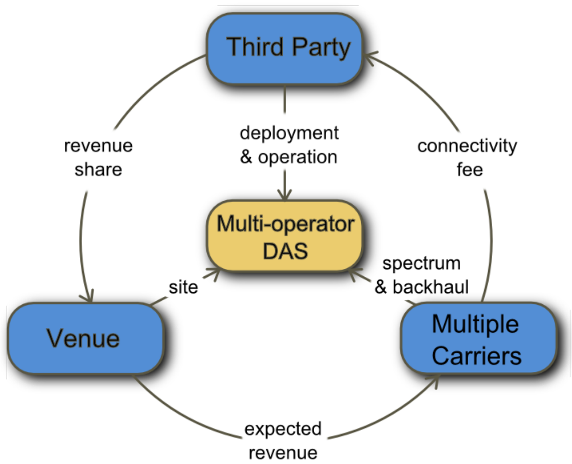


Figure 5.4: Actor configuration when a third party owns the network.

Indoor Infrastructure Sharing

As a strategy to decrease macro network expenses, mobile operators can share networks with competitors on a scale that start on site sharing to core or spectrum sharing deployments, as joint ventures[21]. The degree of sharing depend on a number of factors surrounding operators business as competition, level of thrust in partners, drive for fast time to market of new radio access generations, limitations and conditions imposed by regulators and perspectives on cost reduction.

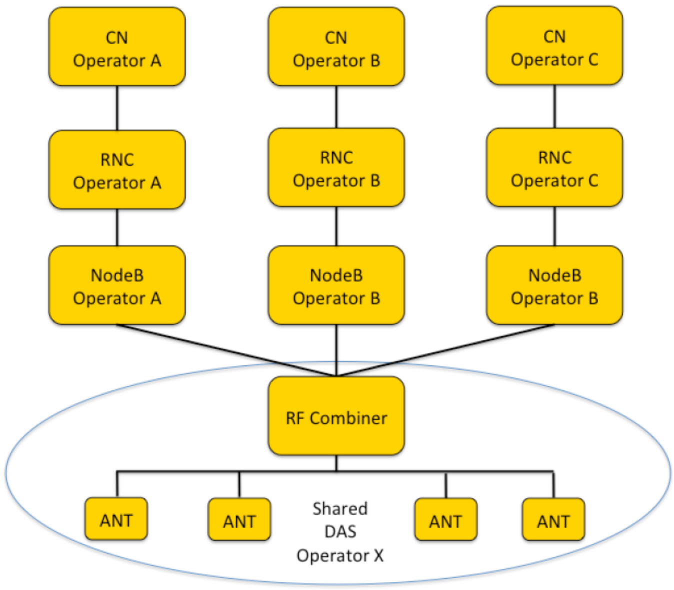


Figure 5.5: Infrastructure sharing with DAS[22].

Indoors, it is common to share the infrastructure, particularly with DAS networks, figure 5.5. Although network sharing has been driven by coverage limitations, capacity constrains can also trigger the same approach to achieve cost reduction. In fact, that is a reason that drives operators to deploy multi-operator infrastructure even if other operators are not interested at the time[5] and which motives them to the resort to neutral host network providers to deploy in-building networks.

Indoor Roaming Agreements

Roaming has been another tool for mobile operators to extend their networks nation wide in a cost efficient way by using each other networks where their own service do not reach. The same approach can be taken to hotspots where the issue is not coverage but capacity, where the network can be congested and fail to provide

[5] Interview with Vodafone Portugal

the QoS users expect. Such deployment model can even be extended to MVNOs that may operate the network for a mobile operator and benefit from his spectrum resources through a roaming agreement, figure 5.6.

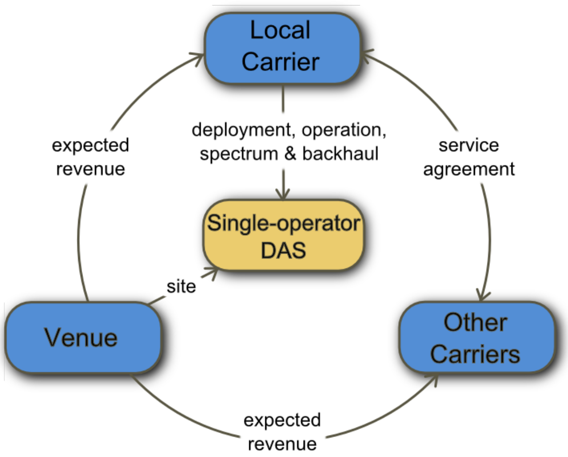


Figure 5.6: Actor configuration with indoor roaming.

This latter deployment model shows that is possible to provide a multi-operator service through a single-operator system by establishing indoor roaming agreements, much like national roaming. However, roaming agreements may have the drawback of a decreased level of control by the operator served rather than an infrastructure sharing approach by deploying a multi-operator system. Moreover, by avoiding the involvement of third parties, there must exist higher levels of thrust between operators which are competing for the same market.

5.3 What deployment options for Radio Dot System?

It is not clear how can Radio Dot System support multiple operators due to the support of a single band with limited bandwidth (IBW 40 MHz)[23]. The most likely scenario is Radio Dot System to be deployed to support a single operator service, in particular the ones represented in figure 5.2 and 5.6. As previously discussed the first option is more suitable for enterprise costumers since operators can count on a subscription package where the revenues may superimpose to the dedicated network investment. However, not all enterprises are willing to be served by only one operator since the BYOD trend is taking over and bringing several devices with different subscriptions inside the premises[22]. On the other hand, indoor roaming is not seen by operators as a desirable situation, it does not allow service differentiation[6].

[6]Interview with Vodafone Portugal

However, the discussion on shared or unlicensed spectrum access schemes can be a game changer. Several schemes for spectrum sharing have been discussed in the literature and sparkled interest among regulators such as Licensed Shared Access (LSA) and Unlicensed Access which will have an impact for local operators running indoor networks. The main proposition of LSA is that there is to some extent a degree of protection of service quality whereas unlicensed spectrum has no restrictions regarding who uses and the number of users, similarly to WiFi bands.

If such ease of spectrum access, while allowing service quality, is put forward by regulators, spectrum is not a resource only accessible to mobile operators. As such, new business models will emerge from such shift and local operators' position on indoor deployment scenarios will be strengthened. In an extreme scenario, mobile operators may only provide connection from core networks to buildings, as fixed network providers, and in-building networks may be managed only by the local operators by taking advantage of lighter licensing as LSA[24].

However, if spectrum sharing evolves towards the aforementioned scenarios, spectrum might not be the main value proposition of mobile operators regarding indoor systems. Moreover, it may push indoor systems towards a single-operator functionality in the sense that separated bands for different operators would not be required, quite similar to WiFi case. As such, changes on spectrum availability will incur changes on business models which affects the drive for single-operator system choice. In particular, the cases depicted in figure 5.3 and figure 5.4 will change where the main difference is that operators provide a link to the building and not spectrum and, in that case, a single-operator solution may be deployed.

However, such approach would resemble WiFi and its advantages brought by unlicensed spectrum would be carried to cellular which is something that operators are not willing to risk.[7] Instead, it is more likely that unlicensed spectrum is used on top of small licensed bands for indoor, particularly because of spectrum aggregation functionality introduced by LTE-A. If so, the question remains for the reasoning behind single operator Radio Dot System. By being both a network vendor and provider, Ericsson may take the place of the third party role seen in figure 5.4 but not as a neutral host third party.

[7] Interview with Portugal Telecom.

Chapter 6

Conclusions

The aim of this chapter is to summarize and emphasize the most relevant findings described in this document while connecting them to the original work objective, expressed through the research questions in section 1.3. The work developed has focused on the scalability limitations of Ericsson Radio Dot regarding capacity, on a cost analysis and single-operator deployment options. In the following, the findings are articulated as answers to the research questions followed by a discussion on future work.

How are coverage and capacity related for Ericsson Radio Dot System regarding an enterprise scenario?

At first, the factors affecting both capacity and coverage were identified and discussed on chapter 3, namely, system limitations, bandwidth and user density. It was found a trade-off linking coverage to capacity which uncovered the dependency on those limiting factors, as depicted on figure 3.9.

Furthermore, an analysis for enterprise buildings was conducted in order to evaluate the feasibility of various bit rates through Ericsson Radio Dot deployment. It was seen that Radio Dot System delivers, however, for higher user densities and larger buildings more than one digital unit is required.

A study considering future traffic requirements was also conducted to see in what ways can Ericsson Radio Dot keep up with upcoming demands. The analysis shown two options, to use more spectrum and to deploy more IRUs. However, at a certain point, such options are not be enough and multicell support may do the trick, as seen in section 4.3 for a cell splitting case.

How does Ericsson Radio Dot System cost compares with femtocell and macrocell networks on an enterprise setting?

A cost evaluation was conducted on chapter 4 to add on to the discussion on scalability started by the previous research question. For the matter, a TCO comparison of Ericsson Radio Dot was made with femtocell deployment and macro outside-in coverage. For the same traffic requirements, it was shown that Radio Dot System has an cost advantage over the alternatives where the biggest margin in seen for larger and lower user dense buildings. Moreover, CAPEX was found to be the dominant component of the TCO, leaving room for improving the cost margin.

In capacity improvement context, cell splitting prove to be an option. Could it also increase the cost advantage of Ericsson Radio Dot over femtocell deployment and macro coverage? As seen in section 4.3 for a particular case, it might decrease CAPEX on 17,5% and OPEX on 16,0%.

To add a spectrum perspective to the discussion, an evaluation of the relative value of bandwidth required was done. Opposed to femtocell and macro layer for indoor coverage, Ericsson Radio Dot is more flexible to adapt to operators spectrum strategy due to an trade-off between number of IRUs and bandwidth.

What are the deployment options for Ericsson Radio Dot System as single operator?

Deployed a single-operator system, Radio Dot System is rather limited on possible deployment scenarios. At the moment, mobile operators and infrastructure owners see a single-operator system viable in enterprise buildings where high revenue is expected, enough to overcome the infrastructure investment. Moreover, national roaming agreements concluded for indoors might be a way to operators leverage the investment with a single-operator solution, however, it is not a common practice yet.

The most likely scenario is that Ericsson sells and operate Radio Dot System for mobile operators. As such, Ericsson need to captivate mobile operators by showing Radio Dot makes the most of their spectrum and that it is cost-efficient, such that infrastructure sharing is not advantageous.

During the elaboration of this study, other relevant trends were identified which are worth mention. It was seen that femtocells are moving in the direction of larger cells, from 16 users to 32 and 64 users supported, and to support multiple operators. At the same time, femtocells are entering otherwise DAS markets as enterprise buildings and public venues. On the other hand, indoor cellular networks seam to approach WiFi technology regarding the use of unlicensed spectrum and the possible business model where the mobile operator resembles a fixed line operator.

Future Work

Some issues have been raised by the results of this work which require further investigation, namely:

- It was concluded that building size and user density influence the capacity of Radio Dot System. How would that translate into cost performance, particularly comparing with femtocells?
- It was seen that a dense macro layer will be needed for future demands and that site reuse is only feasible at some extend. How would cost be compared with femtocell deployment if site reuse was not considered after some base station density threshold?
- The NPV computations where done considering single-operator support. How much would the cost change if the system CAPEX and OPEX were shared among multiple operators?
- The revenues were not included in the NPV computations. Which margin would be expected for NPV if expected revenues were considered for Radio Dot System?

Appendix A

Cost Modeling for Radio Dot System

CAPEX	
DOT	300 €
Copper fronthaul	50 €
Radio planning	50 €
Installation	50 €
Total per DOT	350 €
IRU	1 500 €
Auxiliary equipment	50 €
Fiber fronthaul	110 €
Radio planning	100 €
Installation	200 €
Total per IRU	1 960 €
DU	15 000 €
Auxiliary equipment	500 €
Installation	1 000 €
Total per DU	16 500 €

(a) CAPEX.

OPEX	
O & M	500 €
Power	1 117 €
Total	1 617 €

(b) OPEX.

Figure A.1: Cost structure for Radio Dot System.[1]

[1]The cost of Radio Dot System components was based on a DAS System since no data is available yet.

List of Acronyms

BYOD Bring Your Own Device

CAGR Compound Annual Growth

CAPEX Capital Expenditures

CoMP Coordinated Multi-Point

DAS Distributed Antenna System

DU Digital Unit

EAC Equivalent Annual Cost

eMBMS evolved Multimedia Broadcast Multicast Service

HD High Definition

HSPA High Speed Packet Access

IRU Indoor Radio Unit

LAN Local Area Network

LSA Licensed Shared Access

LTE Long Term Evolution

NPV Net Present Value

OPEX Operational Expenditures

OTT Over-The-Top

PTS Swedish Post and Telecom Agency

ROI Return Of Investment

ScaS Smallcell as a Service

TCO Total Cost of Ownership

VoLTE Voice over LTE

WCDMA Wideband Code Division Multiple Access

WiFi Wireless Fidelity

WLAN Wireless Local Area Network

Bibliography

[1] *Closing the Mobile Data Revenue Gap*. White Paper. OPENET Telecom, 2010.

[2] Jan Markendahl et al. "Business Innovation Strategies to Reduce the Revenue Gap for Wireless Broadband Services". In: *Communications & Strategies* 3rd quarter 2009.75 (2009), p. 35.

[3] Jan Markendahl. "Mobile Network Operators and Cooperation : A Tele-Economic Study of Infrastructure sharing and Mobile Payment Services". PhD thesis. KTH, Communication Systems, CoS, 2011.

[4] Klas Johansson. "Cost Effective Deployment Strategies for Heterogenous Wireless Networks". PhD thesis. KTH, Communication Systems, CoS, 2007.

[5] Zhen Liu. "Techno-economical Analysis of Indoor Enterprise Solutions". PhD thesis. 2013. ISBN: 9788771520255.

[6] Amirhossein Ghanbari. "Indoor multi-operator solutions, Network sharing and Outsourcing network management and operation". MA thesis. KTH, School of Information and Communication Technology (ICT), 2013.

[7] Ashraf Awadelkarim Widaa Ahmed, Jan Markendahl, and Amirhossein Ghanbari. "Evaluation of Spectrum Access Options for Indoor Mobile Network Deployment". In: 2013.

[8] M. Kantor et al. "General framework for techno-economic analysis of next generation access networks". In: *Transparent Optical Networks (ICTON), 2010 12th International Conference on*. 2010.

[9] Harri Holma et al. "Performance". In: *LTE for UMTS*. John Wiley & Sons, Ltd, 2011. ISBN: 9781119992943.

[10] Marty Schmidt. *Capital Expenditure (CAPEX) Explained*. Last accessed on June 2. URL: `http://www.business-case-analysis.com/capital-expenditure.html`.

[11] Marty Schmidt. *Operating Expenses OPEX Explained*. Last accessed on June 2. URL: `http://www.business-case-analysis.com/operating-expenses.html`.

[12] Investopedia. *Equivalent Annual Cost - EAC*. Last accessed on June 2. URL: `http://www.investopedia.com/terms/e/eac.asp`.

[13] Marty Schmidt. *Total Cost of Ownership TCO Explained*. Last accessed on June 2. URL: http://www.business-case-analysis.com/total-cost-of-ownership.html.

[14] Ericsson. *Ericsson redefines small cell market with ERICSSON Radio Dot System*. Press Release. 2003.

[15] Jan Markendahl, Amirhossein Ghanbari, and Bengt G. Mölleryd. "Network cooperation between mobile operators : why and how competitors cooperate?" In: *IMP Conference 2103 :* 2013.

[16] *Successful Network Sharing*. White Paper. Ericsson, 2010.

[17] Bengt G. Mölleryd and Jan Markendahl. "The role of network sharing in transforming the operator business: Impact on profitability and competition". In: 24th European Regional Conference of the International Telecommunication Society, Florence, Italy, 20-23 October 2013. Florence: ITS, 2013.

[18] C. Beckman and G. Smith. "Shared networks: making wireless communication affordable". In: *Wireless Communications, IEEE* 12.2 (2005).

[19] J. Markendahl and A. Ghanbari. "Shared smallcell networks multi-operator or third party solutions - or both?" In: *Modeling Optimization in Mobile, Ad Hoc Wireless Networks (WiOpt), 2013 11th International Symposium on*. 2013.

[20] Ashraf Awadelkarim Widaa Ahmed, Jan Markendahl, and Amirhossein Ghanbari. "Investment strategies for different actors in indoor mobile market : "in view of the emerging spectrum authorization schemes"". In: *24th European Regional Conference of the International Telecommunication Society, Florence, Italy, 20-23 October 2013 :* QC 20140603. 2013.

[21] T. Frisanco et al. "Infrastructure Sharing for Mobile Network Operators; From a Deployment and Operations View". In: *Information Networking, 2008. ICOIN 2008. International Conference on*. 2008.

[22] *Enterprises and multi-operator small cells*. Tech. rep. Small Cell Forum, 2013.

[23] Signals Research Group. "THE DOT - IT'S COOL AS SH&#!" In: *Signals Flash* (September, 2013).

[24] Du Ho Kang, Ki Won Sung, and J. Zander. "High capacity indoor and hotspot wireless systems in shared spectrum: a techno-economic analysis". In: *Communications Magazine, IEEE* 51.12 (2013).