Shared Smallcell Networks

Multi-Operator or Third Party Solutions – Or Both?

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***Abstract* — Network sharing is a commonly used solution for macro cellular networks when mobile operators want to exploit benefits of sharing infrastructure, typically to save network costs. For local area and indoor networks infrastructure sharing using distributed antenna systems (DAS) and repeaters are commonly used solutions to improve indoor coverage. For these applications multi-operator solutions are well known and supported by both standardization bodies and by collaboration practices. However, when local networks are discussed in terms of femtocell solutions, offloading or heterogeneous networks, the multi-operator context seems to be forgotten. Small cells are often presented in a single-operator context. This does not comply with market demand and practices, since facility owners neither want one single mobile operator to dominate the capacity provision nor accept multiple indoor infrastructures provided by multiple mobile operators.**

In this paper we will discuss the business model implications of different multi-operator solutions for indoor deployment. The key findings are in the areas of: i) how multi-operator small cell solutions can fit into existing market practices when it comes to operator business, ii) how local network operators (3rd parties) and outsourcing can play a role in the business landscape, and iii) how different (novel) spectrum allocation and access strategies can play a role for indoor network deployment.

Keywords – Actors, business models, business roles, competition, cooperation, femtocell access points and gateways, indoor network deployment, MOCN, mobile broadband networks, offloading, network sharing, roaming, spectrum access, spectrum sharing strategies, techno-economic analysis, third party actors

I. Introduction

The rapid increase of wireless Internet access services for smartphones, tablets and laptops has resulted in strongly growing demand for mobile broadband (MBB) access services. To meet the increasing demand more radio capacity needs to be deployed while at the same time controlling the increasing network costs in terms of both capital expenditure (CapEx) and operational expenditure (OpEx). For macro cellular networks sharing of base station sites and/or the radio equipment and spectrum are commonly used strategies to lower the network costs [1] [2] [3]. The benefits, drivers, drawbacks and risk with shared networks, with focus on macro cell networks, have been investigated in many papers, e.g. [4] [5] [6] and is quite well understood. However, network sharing for indoor and local area environments using small cell solution needs to be further researched. In this paper we will discuss sharing of small cell networks with focus on business model implications that can be identified for different technical network solutions

Most of the wireless data traffic is generated from indoor or local area locations. Examples are shopping malls, arenas, railway stations, trains, subways, hotels and office buildings where the users typically are employees of companies in the buildings. Facility owners do not want one single mobile operator to dominate the capacity provision. In the same way facility owners do not accept multiple physical indoor networks or infrastructures that need to be deployed and maintained by different actors requiring access to the local environment. Hence, a single shared infrastructure is of interest.

In order to improve indoor coverage two types of solutions are widely used; Distributed Antenna Systems (DAS) [1] and repeaters. Here competing operators cooperate with each other and also with the facility owner and/or with companies using the indoor infrastructure. In this multi-operator settings the physical infrastructure i.e. the DAS network and the repeater equipment, is shared. However, the radio capacity (the base stations), the spectrum and the access control are managed by each operator. For pico- and femtocell networks the situation is different when it comes to sharing. There are multi-operator small cell solutions where both the base stations as well as spectrum and access control are part of the shared solution. In this paper we will discuss two main types of shared networks:

- Multi-operator access to a local radio access network, operated by a local operator, by use of roaming
- Multi-operator access to a common radio access network enabled by gateway or multi-operator core network (MOCN) solutions

For the technical solutions we will discuss the business model implications, the roles and responsibilities for different actors. We will especially look into the role of local network operators and 3rd part actors that can: i) operate networks on behalf of others, ii) offer capacity offload to mobile operators, or, iii) act as an independent local operator. Related to this we will discuss the business model options for outsourcing of deployment and operation of local networks.

The paper is organized as follows: Section II describes related work and our contribution and section III outlines the methodology. In section IV business model options for the technical indoor solutions are discussed. Spectrum and capacity issues are discussed in sections V and VI. Business opportunities for outsourcing of local networks are discussed in section VII. Examples of business models are provided in section VIII using two case studies on local area networks. Conclusions are found in section IX.

II. Related Work and Contribution

A. Related work

For heterogeneous networks joint operation of macrocells and pico/femtocell has been discussed in details [2]. Technical considerations and impairments of Femtocells and the tradeoff between coverage and capacity gains [3] are the other issues discussed in this area. Sharing networks have been discussed for outdoor networks focusing on resource sharing such as spectrum and site sharing [4] [5] [6] where viable business models based on them have been presented [7] [8].

When it comes to indoor networks, DAS approaches have been discussed for a long time [9] [10]. Local Wi-Fi and private networks have also been discussed [1], from which some business scenarios have been presented. On the other hand, ideas regarding sharing picocells as the indoor component of Heterogeneous Networks (HetNets) have been presented [11] where the focus is mainly on cooperation between different network layers [12]. How spectrum can be shared in the picocell layer is presented in [13] [11]. Regarding femtocell, manufacturers and MNOs have mainly discussed deployment of femtocells in their white papers from a single operator point of view, where deployed networks consist of home usage and so called residential femtocells [14]. Deploying residential femtocells for home and SOHO use from a single operator point of view are described in [14] [6]. Techno-economic analysis of indoor network deployment have recently been presented in [1] [15] [16] but multi-operator aspects are considered only in [1]. Regarding management and operation of indoor networks, a few studies on multi-actor public Wi-Fi networks have been conducted [17] that to some extent may be applicable to femtocell business models. Some discussions about profitability of femtocell deployments have been presented [18] [19].

In addition, some assessment of outsourcing managed services for MNOs have been presented where economic issues of outsourcing were considered mostly by Frisanco [20]. Friedrich [21] presented brief insights into the motivation for network outsourcing and the rationale behind vendor selection from the operator perspective. Chaudhury [27] explained the risks and pitfalls that come with network outsourcing deals for network operators in their study, where they provide brief suggestions for the operators, in particular on what they can outsource and on what qualities in vendors that they need to look out for. Finally, Nunna [28] provides a status quo on the phenomenon of network outsourcing by proving an overview of the deals undertaken by major network vendors.

When it comes to spectrum allocation and different types of spectrum access solutions the growing mobile broad band traffic is a strong driver for different types of research. The need for and the benefits of additional spectrum have been discussed in [29] [30]. Different alternatives to allocation of more licensed spectrum are currently discussed, examples are secondary spectrum access, licensed/ authorized shared access (LSA/ASA) [31] [32] [33]. As Zander et al points out in [34] secondary access and LSA and ASA concepts are very interesting for indoor deployment due to low power levels and protection by wall penetration losses.

B. Contribution

Our techno-economic research on wireless indoor solutions targets three overlapping areas: network deployment, network sharing strategies and the role of trusted 3rd party actors. From the related work section we believe that there is a need to look more into indoor multi-operator solutions, both from a technical and a business perspective. We can identify three different problem areas with gaps in the current research:

- Network sharing solutions for small cell networks
- Spectrum sharing and spectrum access strategies for local networks, possibly operated by local operators
- Solutions for commercial small cell networks operated by actors other than mobile network operators

When it comes to spectrum sharing and access strategies we can consider: i) use of licensed spectrum, unlicensed cellular spectrum bands (e.g. in the 1800MHz band) or some form of shared or secondary access. Related to the three problem areas above we have three main research questions:

1. Can femtocell sharing solutions compete with DAS?
2. What spectrum access options need to be exploited?
3. What roles can local operators (3rd party actors) take?

III. Methodology

Due to the explorative nature of the research objectives a qualitative research approach has been used. A first round of interviews was conducted year 2010 and reported in [7]. Here Swedish mobile operators TeliaSonera, Tele2 and Telenor and telecom manufacturers Ericsson, Huawei and Nokia Siemens Networks (NSN) were interviewed about drivers and obstacles of network sharing in general. Interviews were also made about indoor deployment solutions and business models. In addition to the actors mentioned above, interviews were made with the Swedish and UK regulators (PTS, Ofcom), with equipment providers and system integrators (Absolute Mobile, MIC Nordic and Powerwave), with the Swedish real estate company "Jernhusen" and with big organizations using indoor solutions (the Swedish parliament and Uppsala University).

Year 2012 a second round of interviews was done with focus on indoor deployment, shared solutions and the role of third party actors. In addition to telecom manufacturers (Commscope, Ericsson and NEC) we interviewed companies with focus on local network solutions and services (Cloudberry, Icomera and MIC Nordic) and on management of networks of other actors (Ericsson Global Services and 3GNS). We also got valuable input from train companies in the UK and in Sweden (Keolis, SJ, SL and Transitio). The outcome of this second round of interviews is reported in this paper and in [35].

For analysis of the interaction between market actors we have used concepts and ideas from business network research [36] [37]. The ARA model was used to enable the mediation between technology and economic values. We complement this analysis by discussing the value proposition, the firm organization and value chain, and the position of the firm in the value network [38].

IV. BUSINESS MODEL OPTIONS

In this section we will discuss business model options for multi-operator indoor networks using DAS and small cells solutions.

A. *Distributed Antenna Systems*

DAS solutions are commonly used in a way to improve the indoor coverage for voice services. A DAS is a separate infrastructure with transmission and antenna elements where a base station dedicated for indoor users provides the capacity. Sometimes a base station that is shared between indoor and outdoor users provides the capacity of a DAS system.

The DAS systems are divided into two main types, *active* and *passive*. The passive DAS is based on a distribution network based on coaxial cables and antennas. This type does not require any active electronics and is still favoured for smaller installations. In most cases active networks are now installed to match requirements on availability and performance. A DAS system itself is operator and often system independent which maintains the value of the deployment since it is geared to accommodate future standards and operators. A DAS system with multiple operators is shown in Fig. 2.

In the business domain a DAS solution is fully transparent since each operator provides the capacity using own radio equipment and spectrum. An operator can independently provide more capacity to its own indoor users by upgrading the base station equipment. The indoor cells are part of the overall operator network, the base stations in the radio access network of each operator are connected to the respective core networks. From a business perspective this is *business as usual* for the mobile operators, the operators fully control their own cells and there are no potential problems when it comes to sharing of the radio resources. In this case the role of a third party actor can be to own and/or to maintain the indoor DAS infrastructure. The ownership of the DAS system does not have any implications when it comes to the end-users or the traffic.

B. *Multi-operator smallcells using common frequencies*

The femtocell networks include two types of nodes, the Femtocell Access Points (FAPs) and Femtocell Gateways (FeGW). The FAPs have built-in functionality for an adaptive and distributed radio management enabling self-configuration and self-optimization. The FAPs are connected to the operator core network using FeGWs and Internet connectivity. In section V we will discuss spectrum allocation for femtocells.

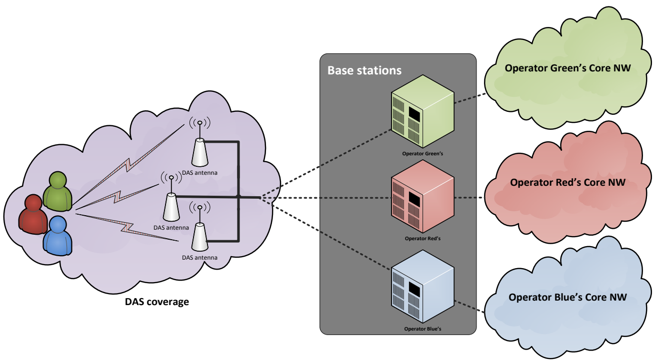

Fig. 1 Distributed Antenna System

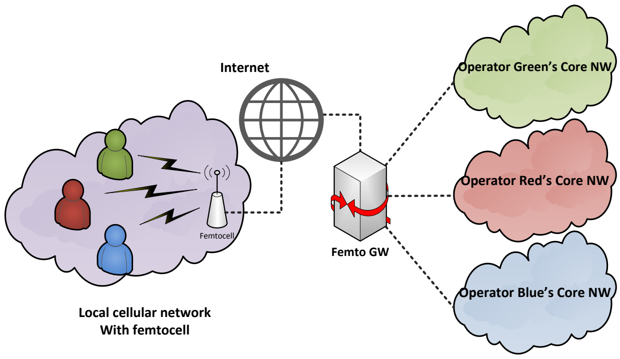

Fig. 2 Multi-operator access using FeGW (the MOCN approach)

One form of multi-operator network is shown in in Fig 2. The radio access network involves FAPs and the FeGWs that manage the access points. In this case the operators share the same frequencies and the FeGW forwards to the traffic to the desired core network. This is one way to implement a multi operator core network (MOCN) solution commonly used for macro base stations [12]. Due to this feature the operators control their users and traffic, a potential problem is how the resources should be shared between operators..

With this solution the operators need to agree on what frequencies to use and how to deploy and operate the femtocell network. One mobile operator can deploy and operate the network making use of its own frequencies. Alternatively a third party can deploy and operate the femtocell network on behalf of the operators, still frequencies needs to be allocated for specific location.

C. *Multi-operator smallcells using dedicated frequencies*

A multi-operator femtocell network using different sets of frequencies for different subscriber groups are shown in Fig 3. Equipment manufacturers outline two ways to implement this multi-frequency feature: i) put two or more femtocells in to one "black box" or ii) put two (or more) chipsets in one femtocell device where each of them controls one dedicated frequency. With this approach the gateway should be located in the same premises in order to distinguish between different operator traffic and be able to send different streams of traffic over the internet. This is similar to the macrocell multi-operator RAN (MORAN) solutions that were presented after year 2000. For the operators this is very similar to the DAS approach since the traffic and frequencies are fully separated.

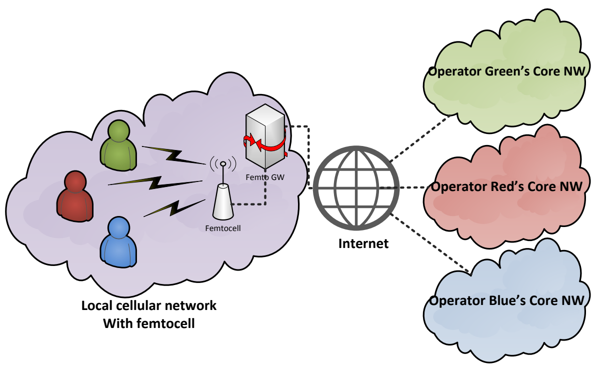

Fig. 3 Multi-operator access using FeGW (MORAN approach)

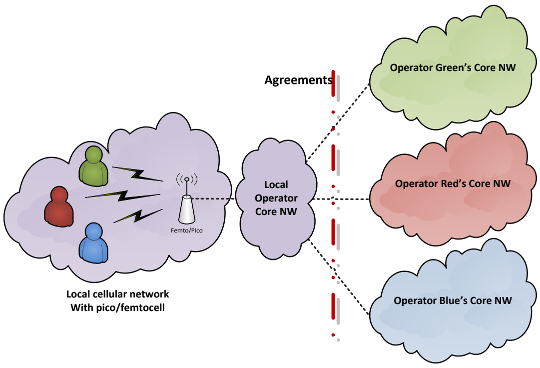

Fig. 4 Multi-operator access using local roaming

D. Multi-operator access using roaming

With a roaming approach we consider a mobile or local operator that deploys and operates a separate local network. Other operators and their subscribers can access the local network using local roaming, see Fig 4. This is similar to national roaming used by mobile operators and the terms and conditions for the usage require business agreements. Technically we denote this solution "roaming" but for the discussion of options for business models and frequency allocation we can identify two main cases depending on what actor that deploys and operates the local network: a traditional mobile operator or an independent (smaller or local) operator.

1) A local network operated by a mobile operator

A mobile operator has dedicated licensed spectrum and this would be the first choice. However, mobile operators tend to be unwilling to allocate separate frequency bands for exclusive use in indoor locations [7]. In addition, if the same frequencies are used for both macrocells and femtocells the operators are faced with network planning and interference challenges. An option could be to use unlicensed cellular bands, e.g. 1800 MHz, which have been allocated by some telecom regulators.

When it comes to business model options we believe that a mobile operator that deploys this type of local network enters a roaming *business* and where this effort is part of a cooperation strategy with other mobile operators. However, these types of activities require many and good relations with facility owners, something that may not be within the core business of typical mobile operators.

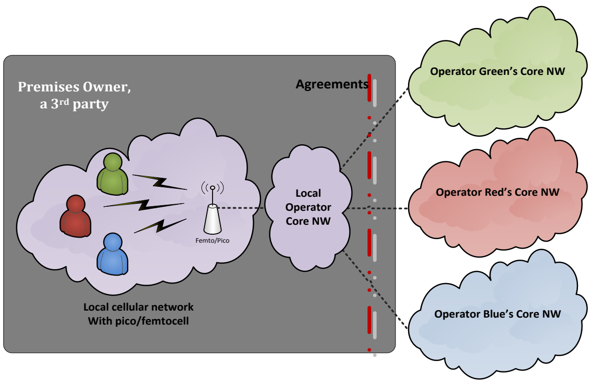

Fig. 5 A local actor (e.g. a premisses owner) with a femtocell network acquring a core network becoming "an operator"

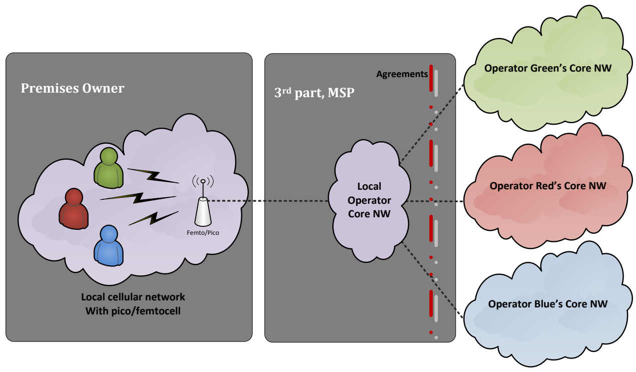

Fig. 6 A local actor (e.g. a premisses owner) with a femtocell network cooperates with an operator with a core network.

2) A local network operated by an independent actor

For an actor without licensed spectrum the spectrum allocation is of crucial importance, *no spectrum means no business*. This is different to mobile operators that have spectrum and can face some planning or interference problems. The spectrum allocation options will be discussed in section V.

For an independent local actor the main driver would be to enter an *offloading business* where capacity and access to indoor and local area networks are offered to mobile operators. A number of options exit for distribution of resources and roles between actors. The 3rd party actor running the indoor radio access network can acquire core network elements, a network code and an operator license and be an operator, see Fig 5. As an option the 3rd party can cooperate with some other operator already having these assets, this is illustrated in Fig 6.

V. SPECTRUM ALLOCATION AND ACCESS

For both mobile operators and 3rd party actor it is of interest to investigate alternatives to traditional licensed bands. Mobile operators want to avoid interference or to "waste" licensed bands and for 3rd party actors control of spectrum is a key to enter the business.

The recent allocation of unlicensed bands in the 1800 MHz band in countries like UK, Sweden and the Netherlands enable any actor the possibility to offer GSM voice services in local environments. This offers the possibility to use cellular technology without any need to involve mobile operators. The GSM handsets are already available; another driver is that new smartphones will have LTE in the 1800 MHz band.

For indoor and low power system another option is to exploit frequency bands allocated to other types of systems and applications. An example is broadcasting and the use of TV white spaces, i.e. TV channels not used at a specific location. Other examples are use of aeronautical bands just above 1 GHz and radar bands in the range 2.3-3.4 GHz [33] [34].

A key aspect here is that manufacturers of networks and user devices really will support the radio access technologies in these spectrum bands. The lack of manufacturer support is often mentioned as a major weakness for cognitive radio and secondary spectrum access solutions. However, more long term, investment friendly and less risky approaches like LSA are currently discussed [32].

Another important aspect of spectrum allocation is the co-existence of macro and femto/picocll layers. One well know example for closed access femtocells are the coverage holes that appear around femtocells for devices connected to distant macro base stations using the same or adjacent channel [7]. Standalone bands dedicated for small cell use hence would imply two type of benefits to mobile operators: i) avoidance of interference with macrocells and ii) bands below 3GHz can be used for wide area macrocell deployment. Hence, roaming or 3rd party indoor solutions not using licensed operator spectrum will provide additional benefits to mobile operators.

VI. Capacity Comparison

Another aspect of shared indoor networks and the choice between DAS and small cell solutions to consider is capacity. DAS systems have the capacity of macro base stations and small cell solutions with many nodes provide a very high capacity. This can be illustrated by a capacity-demand analysis where we compare the number users that can be served [42].

Assume that the indoor users consume 10 GB per month today and will consumer 50GB in the "future". The data is consumed during 8 hours of the day (all equally busy) during 30 days. This corresponds roughly to average bit rates 0,1 and 0,5 Mbps, note that this is average number used for capacity estimates. We consider small cells using 5 or 20 MHz of spectrum and DAS systems using 20 MHz of spectrum. In order to do a sensitivity analysis in the dimensions demand, allocated spectrum and deployment strategies we also vary the spectral efficiency and use the values 1 and 10 bps per Hz. This can be compared to the 3GPP and ITU target values of 15-30 for the peak values and around 2 for the cell averages. In an indoor environment the spectral efficiency will be well above 1 bps per Hz. The values in table I indicate that the following number of users can be served per node

- 50 – 500 10GB users or 10-100 50GB users with a 5 MHz femtocell
- 200-2000 10GB users or 40-400 50GB users with a 20 MHz picocell or DAS system

This sensitivity analysis has two major implications. First, the small cell solutions provide very high capacity; the indoor systems will not be capacity limited. Sharing of small cells is perfectly OK from a capacity perspective.

Secondly, the DAS systems will have capacity limitations, especially for future "high" demand levels. In large buildings there will more than 40-400 users. However, a DAS system can be "sectorized", e.g. by deploying one "sector" per floor.

Table I Comparison of (theoretical) number of served users

System bandwidth (*MHz*)	Spectral efficiency (*bps / Hz*)	System Capacity (*Mbps*)	No. served 10GB users	No. served 50GB users
5	**10**	**50**	**500**	**100**
5	**1.0**	**5**	**50**	**10**
20	**10**	**200**	**2000**	**400**
20	**1.0**	**20**	**200**	**40**

VII. Outsourcing and the Role of 3rd Party Actors

The operation and management of each indoor network, based on the used sharing model, can be either done by the operator itself or an authoritative outsourcee. In some models it is quite more relevant to outsource O&M to one singular outsourcee. For instance, in case of MOCN sharing, since the FeGW is located at the customer's premises and shared among different operators, it is more admissible to operate the network by one singular outsourcee who controls the existing Smallcell network and FeGWs. Another case of outsourcing O&M in Smallcell networks can be in implementing comprehensive systems. In case of such a wholesale sharing approach, it is the authoritative third party that is acting as a full outsourcee of network operation and management for respective MNOs.

It can be depicted that the Operational Expenditure of an indoor network could be broken down typically as listed below, of which Customer Relations (customer acquisition, customer retention and customer services) enfolds the biggest portion, at the same time Network OpEx embraces a bigger effect on operator's policies.

- Network OpEx
- Customer Relations (CR)
- Interconnect
- IT

The operational costs represented as IT costs are the IT functions of the company which are mainly administrative and not much related to network operations. On the other hand, the second valid option would be outsourcing Network Operation by accepting the change in business landscape described earlier. Regardless of the cost structure of any mobile operator, either a MNO or a MVNO, the most expensive segment of the expenditures for any Smallcell network would be customer relations, considering that CapEx is relatively quite low for Smallcell networks. Therefore, this situation makes the business models complex for network operators in terms of gaining revenue at the same time handling costs. As a result, companies need to focus more on their core business and try to lessen the burdens brought by technical functions.

Two major groups can be mentioned as valid outsourcee's: telecom network vendors and independent 3rd party actors.

A. Telecom network vendors

The first group that already acts as MSP for network operators in case of macrocell networks around the globe is telecom network vendors like Ericsson and Nokia Siemens Networks. Since these companies are the specialists in developing and manufacturing specialized telecommunication devices, they better know how to manage them technically in the most efficient way. It should also be added that MNOs also trust their networks' infrastructure supplier when it comes to outsourcing the same networks' operation. The second candidate then would be a company with fewer resources than infrastructure vendors, in terms of specialization in manufacturing equipment, but at the same time enough O&M capabilities as well as some connections. Less complexity of their business models as well as higher efficiency due to simplicity of their organizations in comparison to the first group is an advantage for this group.

B. *Multi-operator access using roaming*

Some actors deploy local radio access networks and offer this as a service to mobile operators, this is called Small Cell as a Service (SCaaS) and is illustrated in Fig. 5. SCaaS is an emerging model that allows third parties to roll out a Smallcell network and then rent it to several operators thereby lowering the barrier to entry for deployment and total costs [43].

In this field, over the second quarter 2012, Virgin Media announced it is trialing LTE small cells in the UK ahead of launching its Small Cell as a Service offering and Colt Telecom announced it is already in trials with a major European operator. Furthermore, two new companies Cloudberry Mobile and ClearSky have launched their own offerings in Europe and the US, respectively, targeting smaller operators. Without deploying large numbers of Smallcells the mobile network simply could not sustain the continued growth in data usage. Such a dramatic network transformation opens up interesting new. It allows third parties to build networks that several mobile operators can use, thereby reducing costs and time to market. At the moment, this is being targeted at major operators that are looking for a simple route to establish a small-cell network as well as smaller players that have found the barriers to entry too much to enter.

C. *Example of an indoor mobile network ecosystem*

An example of actors and relations for provisioning of Small Cell as a Service (SCaaS) is shown in Fig.7. In this model the MSP is the main actor in the ecosystem playing all the major parts. MSP deploys and operates the network on behalf of any MNO/JV trying to enhance the quality of their network by expanding the coverage as well as increasing the capacity of the their overall network. This is done by means of densification of the network by deploying femtocells indoors. The MSP also takes care of the relations needed with the premises owner on one hand and the relations with NW vendors during the supply chain on the other hand. There might be some business relations needed between premises owner and the MNO/JV in the initial steps in regard to bind some needed agreements but since the main procedure is through the operational period it can be avoided in the scheme.

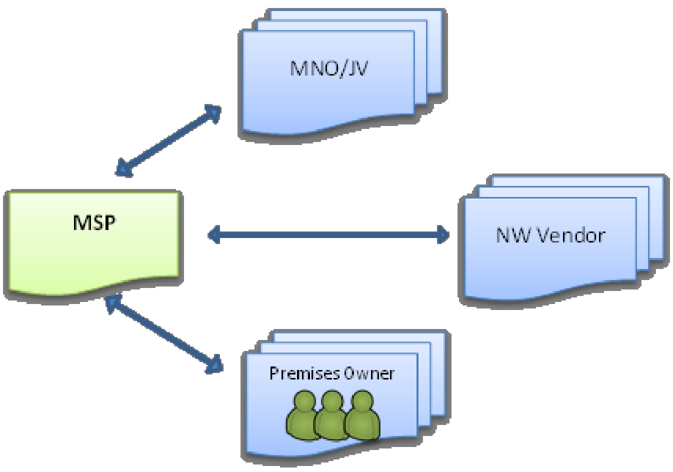

Fig. 7 Example of actors and relations for outsourcing of operation and maintanance in Smallcell networks

VIII. Case Studies

A. *CloudBerry Mobile: better coverage & offloading capacity*

Indoor networks could be implemented to help operators overcome cost and capacity challenges for mobile operators by offloading data from macrocell networks to smaller available cells for indoor users.

Cloudberry is a startup company that provides small cells to consumers and enterprises in Norway. It provides mobile coverage and capacity where the customer needs it. Cloudberry is the first small cells operator in the world which is using its experience to provide small cells services wholesale to other mobile operators in Europe and elsewhere[1]. Cloudberry targets the smaller network operators in European countries, typically the 3rd or 4th, who do not have such large network assets as their larger competitors. Cloudberry's solution may also be attractive to some MVNOs

Cloudberry offers Small Cell as a Service, where a Smallcell gateway (FeGW) is hosted and all the logistics of rolling out residential and enterprise femtocells are remotely operated. The Cloudberry case is illustrated in Fig. 5. In cooperation with a single mobile operator the frequencies of that operator is used.

B. *Onboard train solutions*

According to the UK regulator "Ofcom" technical problems of the so called "not spots" onboard trains are explained as a combination of mobile network coverage problems and attenuation of the signals inside the train carriages. Commercial challenges are said to arise from "lack of immediate benefits to the major mobile network operators to extend good coverage along the full length of all rail routes and lack of financial incentives on the train operating companies to implement physical enhancements to their trains to enable better signal delivery for voice signals. This is from a UK perspective where for Sweden the situation is slightly different.

For repeater systems the Swedish operators join forces and deploy a common onboard system where costs are shared, hence it is not the train operators that make the investments. Another difference is that Swedish operators usually agree on a common onboard system whereas UK and German operators deploy single operator systems onboard trains as part of cooperation with the train company.

The possibility to use unlicensed 1800 MHz band for an onboard local train network for voice services has been identified. This local network can be seen as a "moving cell" where the connectivity to the train is provided by multiple cellular links using 3G and/or 4G technology [8]. This is the same approach that has been used for years where an onboard local Wi-Fi network provides data services.

The local network can be provided by the "facility owner", i.e. the train company. The mobile operators can access the onboard train system using roaming. The train company can be "a local operator" according to Fig 6 or cooperate with another operator as illustrated in Fig 7.

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[1]Exclusive interview with Geir O. Jenssen, CTO Cloudberry Mobile

IX. CONCLUSIONS

Most of the wireless data traffic is generated from indoor or local area locations like shopping malls, arenas, railway stations, trains, subways, hotels and office buildings. Here, shared local networks are highly interesting. Facility owners neither want one single mobile operator to have a local monopoly nor that multiple physical indoor infrastructures to be deployed. For indoor networks infrastructure sharing using distributed antenna systems (DAS) and repeaters are commonly used. The same is true for sharing of macrocell networks. For these cases multi-operator solutions are supported by both standardization bodies and by collaboration practices. However, when local networks are discussed in terms of femtocell solutions, offloading or heterogeneous networks, the multi-operator context seems to be forgotten. Small cells are often presented in a single-operator context.

This lead to the first research question addressed in this paper: *Can femtocell sharing solutions compete with DAS?*

Small cell solutions have cost and capacity advantages [7][21] so why are operators hesitant to use these solutions? One reason may be that operators may see a risk to lose control of its own users and traffic. For the cases of network sharing of macrocells, DAS systems and repeaters the radio capacity (the base stations), the spectrum and the access control are (or can be) clearly managed by each operator. We believe that the control aspect is important to consider on order to get operators more interested in shared smallcell networks.

For both mobile operators and 3rd party actor it is of interest to investigate alternatives to licensed bands. Mobile operators want to avoid interference with macrocells or to "waste" licensed bands and for 3rd party actors control of spectrum is a key to enter the business. This leads to the second question: *What spectrum access options need to be exploited*?

In the short term the use of unlicensed 1800 MHz bands for GSM and LTE should be investigated. Is the allocated bandwidths (5 MHz or less) enough for efficient deployment. In the long term the possibility to use special indoor bands, either exclusively or using shared access, should be analyzed. Here shared access with radar bands above 2GHz is an interesting option.

The last research question addresses technical and business solutions for commercial small cell networks operated by actors other than traditional mobile network operators: *What roles can local operators (3rd party actors) take?*

Owners of office buildings, shopping malls, etc. and transportation companies can exploit the control of the local environment (and the users). These actors can exploit their position by either deploy and operate a local network by themselves or by letting a third do this. In both cases the local network can either be part of mobile operator networks (DAS; MOCN or MORAN approaches) of the local network can be accessed using roaming. In the latter case the local operator need to acquire core network nodes and a network codes and act as an operator, or to cooperate with an operator with these resources and assets. We have also identified the new concept "smallcell as a service" where 3rd party actors offer capacity and offloading to traditional mobile operators.

Eventually, since small cells can satisfy required indoor capacity, if operators dedicate a specific part of their bandwidth to their small cells they can avoid interference to a considerable extent by avoiding co-channel operation but still the likelihood of some interference is conceivable due to adjacent channel operation. But it is still negotiable that operators mainly do not tend to "waste" the frequency in this form. As a result, the proposed MOCN sharing model would exploit interference avoidance by stacking up enough bandwidth for deploying shared smallcell networks by contribution of all participating MNOs. On the other hand, Roaming also enhance interference avoidance since a different frequency, compared to operator's original frequency for macrocells, is being utilized. Where it also highlights the presence of a local operator that only deploys smallcell networks and lease coverage and capacity (on demand) to existing MNOs and can facilitate the situation by using its own frequency (either licensed or unlicensed). This concept is a major driver for the wholesale sharing approach introduced by a full network O&M outsourcee (wholesale sharing), discussed in section VII.

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