Adaptive and Resilient Solutions for Energy Savings of Mobile Access Networks

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Abstract

Continuous development and evolution of mobile communications toward end user expectations has led to heterogeneous mobile networks in the most general sense of the word. The mixture of core network infrastructures and radio access technologies, due to the arrival of new technologies while older ones are still used and not fully exploited, brings mobile operators to a complex business environment. Such a situation threatens future profit margins since the cost of running mobile networks rises with greater pace than total profit. A significant share in the total costs of running a mobile network belongs to energy consumption. Decreasing energy costs by designing hardware with low-energy consumption characteristics and site collocation is already under way, but additional sparing could be achieved through soft solutions or adaptive networks. To reduce operational costs, the crucial role will be played by the self-organizing network paradigm, featured by network management systems and operations/business support systems. In this paper, the authors provide an overview of adaptive and resilient concepts appropriate for improving the energy efficiency of mobile access networks. More precisely, they present the most promising self-organizing network solutions in the radio access and backhaul part of mobile networks; the implementation of which can bring a synergetic effect in terms of significant energy savings.

Keywords: base station, cellular, energy efficiency, heterogeneous network, self-organizing networks, wireless

INTRODUCTION

The development of mobile networks, across all phases and generations, is a race to fulfill end users' expectations. Definitions of mobile network generations are preceding real implementations. Such definitions mostly rely on state of the art radio communications and strongly push further development. Today, the main development drivers are, on one side, mobile broadband services, and on the other one, reducing operational (OPEX) expenditure and capital expenditure (CAPEX).

Users expect mobile broadband services to be comparable with those provided by fixed networks. With proliferation of mobile smart phones followed by mobile applications and services, conservative estimations predict that network traffic will grow 20 to 30 times over the next five years (Marshall, 2012). Improving existing networks by introducing advanced technology such as long-term evolution (LTE) and utilization of new spectrum resources, however, will not be enough (Marshall, 2012; Landstrom, 2011). A promising expansion strategy is to create a heterogeneous network consisting of low-power nodes to complement the macro mobile network layer. Generally, this means complex mobile networks with different Radio Access Technologies (RAT), including Wireless Local Area Networks (WLANs) and a mixture of macro cells with micro, pico and femto cells.

Growing demand for data services does not necessarily translate to an increase in profits due to commoditization, operating complexity, and operational/capital investment. Therefore, the cost of running these mobile networks becomes a very important issue. Further development and evolution toward high-quality services, as well as public availability, could be jeopardized by the overall expenditure of running these communications networks.

With rising energy prices, base stations (BSs) are the most significant energy consumers in the wide area cellular networks and contribute up to 50 percent of the total operational expenditure (OPEX) of an operator (Correia, 2010). This is because the off-grid BSs in remote areas generally use diesel powered generators, which can cost ten times more in comparison with BSs connected to the electrical grid—they are also estimated to have an average yearly OPEX equal to $3,000 (Hasan, 2011). Hence, improving the energy efficiency of wide area wireless networks turns out to be an important economic issue since reducing energy consumption translates into the lowering of an operator's OPEX.

With such an "*all heterogeneous approach*" and foreseen dynamic optimization, the overall complexity of mobile telecommunications is growing. Complexity in the information technology (IT) industry was recognized as the main challenge by IBM research at the turn of the century. As a solution, they came up with autonomic computing; a computing system that can manage itself according to high-level policies defined by administrators. Self-management with its four self-x aspects, namely self-configuration, self-optimization, self-healing and self-protection, is the essence of autonomic computing systems (Horn, 2001; Kephart, 2003). The name, idea and principles behind autonomic computing are borrowed from the human autonomic nervous system.

The communications industry or newly integrated information and communications technology (ICT) industry are experiencing the same complexity problems, but on a bigger scale. These issues are similar to autonomic computing, but are more focused on the foundational rethinking of communication and networking in autonomic communications research. While autonomic computing is directly oriented towards application software and the management of computing resources, autonomic communication is focused on distributed systems and the management of network elements. Both research areas recognize the need for decentralized algorithms and control, context-awareness, and self-x properties (configuration, monitoring, adaptation, and healing) (Dobson, 2006).

Envisioned paramount tools for reducing complexity and growing operational costs of mobile communication networks are self-organizing networks (SONs). The main concept of SONs is that the network should self-organize and manage its elements in order to achieve optimal network quality and performance. The SON is defined around broadly agreed cases grouped into functional domains (NGMN, 2008). Such functional domains cover all aspects of network operations, but more

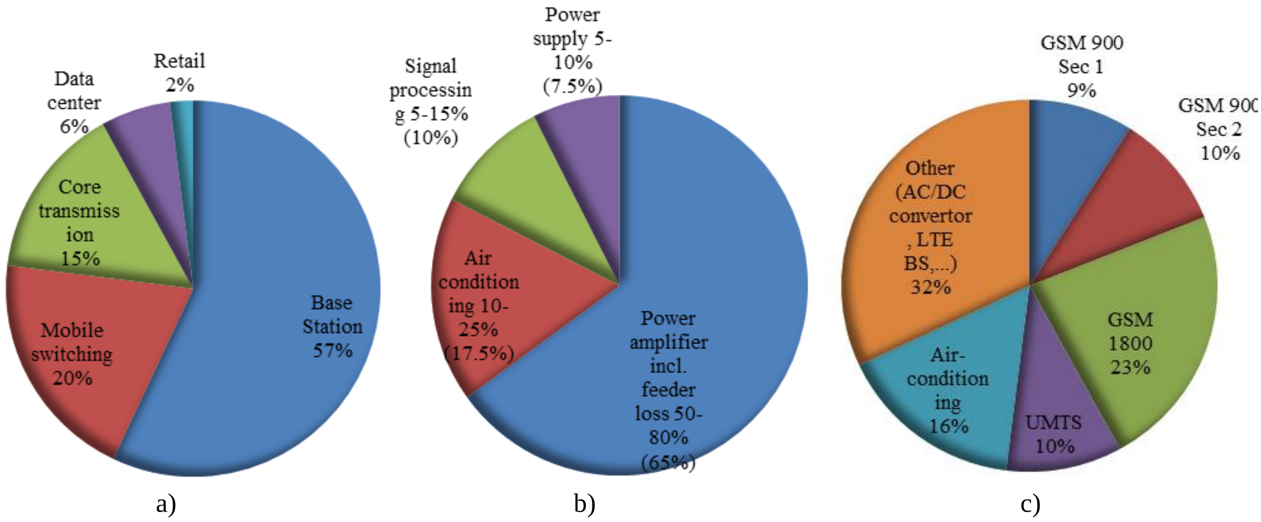

Figure 1. Power consumption of: a) typical wireless cellular networks (Lister, 2009); b) a single BS (Chen, Zhang & Zhao, 2010); c) a single BS site (Lorincz, Dimitrov & Matijevic 2012).

specifically include: self-planning, self-configuration, self-optimization and self-healing (NGMN, 2006; 3GPP TS 36.300, 2013). Energy saving is the SON use case which deals with energy expenses. Its baseline is that energy expenses can be reduced by matching network capacity—as close as possible to real traffic demand at any moment (Feng, 2008; 3GPP TR 36.902, 2011). The SON is mostly related to the LTE, but it is also a general framework applicable to other access networks and is considered a core part of mobile networks (NGMN, 2006; Stewart, 2012). There is also a strong need for an optimized Network Management System (NMS) that will host, orchestrate and enforce SON mechanisms and algorithms, including those related to energy savings.

The rest of the paper is organized as follows. The energy savings section will bring a qualitative analysis of power consumption and introduce energy efficiency in mobile networks. An overview of heterogeneous cellular communication networks is presented in the heterogeneous networks section. Next section is dedicated to a description of the SON and energy savings as the SON use case. The penultimate section considers SON energy savings architecture and NMS capable of hosting SON techniques. Concluding remarks and future work are presented in the last section.

ENERGY SAVINGS

Mobile operators' OPEXs are three times higher than CAPEXs and are estimated to total $400 billion to $500 billion annually, worldwide (Valdecantos, 2008). More recently, (Holden, 2011) estimates operators' revenues to be more than $1,000 billion (one trillion) annually by 2016. The same report predicts that operators' costs will increase and exceed revenue in the same period. Energy consumption significantly impacts the total cost of running a mobile network. In particular, energy expenses are 18 percent of network OPEX in saturated European markets, while in India these figures increase by at least 32 percent due to the use of diesel to power off-grid BSs (Lister, 2009). When we roughly normalize all these numbers the bottom line is: annual energy expenses are approximately 19 percent of the total cost of running mobile networks, or about $190 billion worldwide. Additionally, for the purpose of comparison we roughly estimate operators' total capital investment in networks to be equal to $250 billion, which is only 24 percent higher than annual energy expenses on a global level. Therefore, it is evident that previously neglected energy costs will be a major concern.

The most prominent energy consumers in mobile networks are further presented in

b) c)

Figure 1. According to Fig. 1(a), it can be noticed that the major power consumers are BSs (Lister, 2009). Shares in the total mobile network energy consumption of BSs can be up to approximately 80 percent (Han, 2011; Guo, 2011). As shown in

b) c)

Figure 1(b), the power amplifier as an individual component is the largest energy consumer in the BS, with a share of 50-80 percent in total BS energy consumption (Chen, Zhang & Zhao, 2010). When we scale up to the level of a complete macro BS site containing BSs of different technologies and equipped with an air conditioner, distribution of energy consumption is presented in b)

c)

Figure 1(c) (Lorincz, Dimitrov & Matijevic 2012). Generally, it can be noticed that BSs of older technologies (2G: GSM 900 and 1800), in comparison to newer ones (3G: UMTS and 4G: LTE), will have more influence on the total energy consumption for the site. In cases where BSs are from newer generations (technologies), this is primarily due to improvements in power amplifier efficiency (Hirata, 2010; Ferling, 2010), signal processing techniques, and integrated circuit architectures (Zoican, 2008). This confirms that technological improvements in the development of BS hardware components can also contribute to the improvement of BSs energy efficiency.

The energy efficiency of a wireless access system is considered within three categories: link, equipment and network (Correia, 2010). At the link level, managing control signals in the case of signaling and synchronization channels, and the implementation of micro sleep modes where BS suspends transmission in the order of milliseconds, can contribute to improvements of BS energy efficiency. Equipment or element level comprises energy evaluations of individual components. At the network level, the whole network is analyzed from an energy efficiency point of view, while also considering capacity and coverage of the network. For every category, the specific energy efficiency metrics are defined (Hasan, 2011). On the equipment level, currently the main focus is on increasing the power amplifier efficiency, minimizing feeder losses, and avoiding air conditioning in the cabinets (Blume, 2010).

However, this is not sufficient for obtaining considerable energy savings due to two factors. The first considers the lifetime of BSs, spanning to more than 10 years, as this prevents network operators from performing frequent upgrades to newer BSs that are generally more energy efficient. Secondly, the fact that the service of new technologies (such as LTE) starts to be offered to users imposes the allocation of additional macro BSs of that technology, which must offer a new layer of service coverage. Although BSs of newer technologies such as LTE are more energy efficient, they contribute to an increase in the number of installed BSs. In turn, this increases the size of the backhaul network, network management complexity, and overall energy consumption.

Hence, to obtain significant energy savings, approaches on the network level, in combination with improvements of BSs energy efficiency on link and element levels, must be implemented (Han, 2011). Network level approaches are primarily dedicated to the energy efficient management of network resources in accordance with space and time variations of end user traffic (Blume, 2010). A few network level technologies address power efficiency, such as cognitive radio and heterogeneous networks. Cognitive radio enables transceivers to use the best wireless access in its vicinity by automatically adapting radio parameters. In the case of improving network energy efficiency, this adaption can include spectrum sharing (Oh, 2011) or bandwidth allocation (Chen, Yang & Zhang 2011). Lower frequency bands used for different purposes by mobile operators (e.g. 700 MHz television broadcast band) can be shared what results in better penetration capability, and thus larger coverage for the same transmission power. On the other hand, energy savings through bandwidth adaptation can be performed, since maintaining the same power spectral density for the case of channels with smaller bandwidth requires less radiated power.

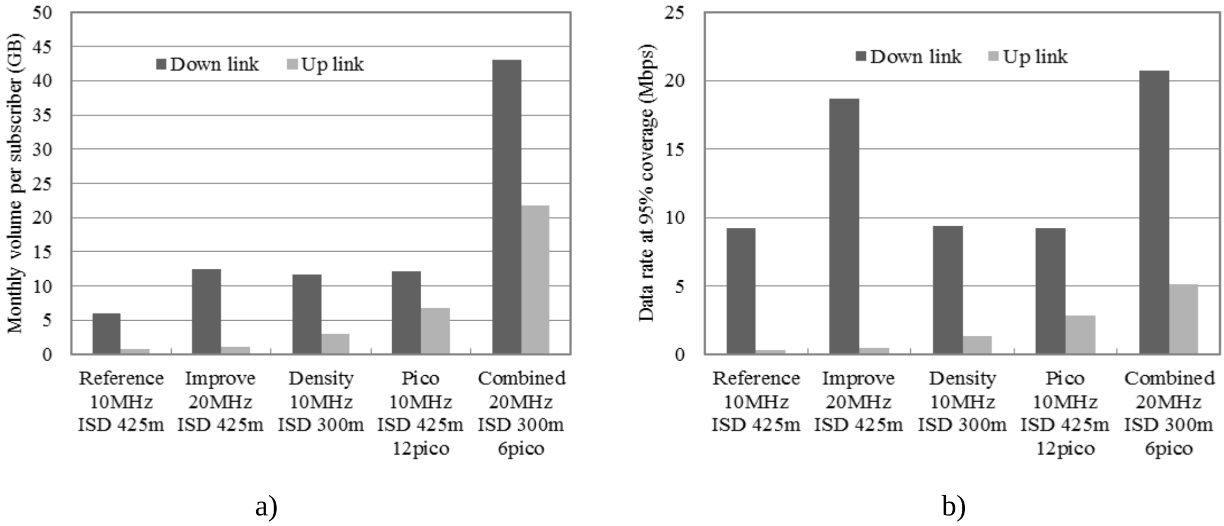

Figure 2. Performance evaluations of expansion strategies for: a) mobility volume per subscriber and b) data rate at 95 percent coverage.

Energy management in heterogeneous networks with smaller cells is based on the on/off switching of unutilized or underutilized BSs, and the adjustment of BS transmit (Tx) power without compromising coverage and quality of service (QoS) in periods of lower user activity. In cellular networks, this is possible due to coverage planning characterized with multiple overlapping layers of cells and capacity planning estimated for accommodating the highest traffic load during peak hours. It is shown that the scaling of BSs Tx power can contribute to improvements of commonly accepted energy efficiency metrics of the cellular networks, such as area bit per joule (kbit/J/km^2) and area power consumption (W/km^2) (Lorincz, 2012, p.161). According to (Lorincz 2012, p.24), significant monthly energy savings (between 35 and 57 percent on the level of a complete cellular network) can be achieved if on/off switching and Tx power scaling of macro UMTS BSs is implemented.

Despite a relatively large number of small cells which must be added to the network, solving capacity issues with such a heterogeneous network approach generally saves energy. The reason is that small cells are much closer to users and the impact on energy savings—due to the use of low power nodes—is still higher than additional power consumption introduced with the deployment of new cells. However, including a large number of low power nodes will have some side effects. These will be reflected in the power consumption of a backhaul mobile network, which will become a significant portion in total network power consumption (Tombaz, 2011). For that reason, the topology of the backhaul mobile network could be optimized since it is designed for peak loads. During some periods, such as at night, the traffic load in wireless access networks can be 5 percent of the peak load (Lorincz, 2012, p. 4310). A lower load could be supported by a simplified network topology, which in turn allows switching off some links and line cards to save additional energy in the backhaul network.

HETEROGENEOUS NETWORKS

Mobile data surpassed voice on a global basis during December 2009, with approximately 140,000 terabytes per month in both voice and data traffic. Furthermore, data traffic is expected to double annually from 2010 to 2015 (Ericsson, 2010; Marshall, 2012). The cellular communications industry and mobile operators are already preparing for throughputs of the order of tens of mbps, both for indoor and outdoor usage, and gigabytes of traffic volumes per subscriber per month (Landstrom, 2011).

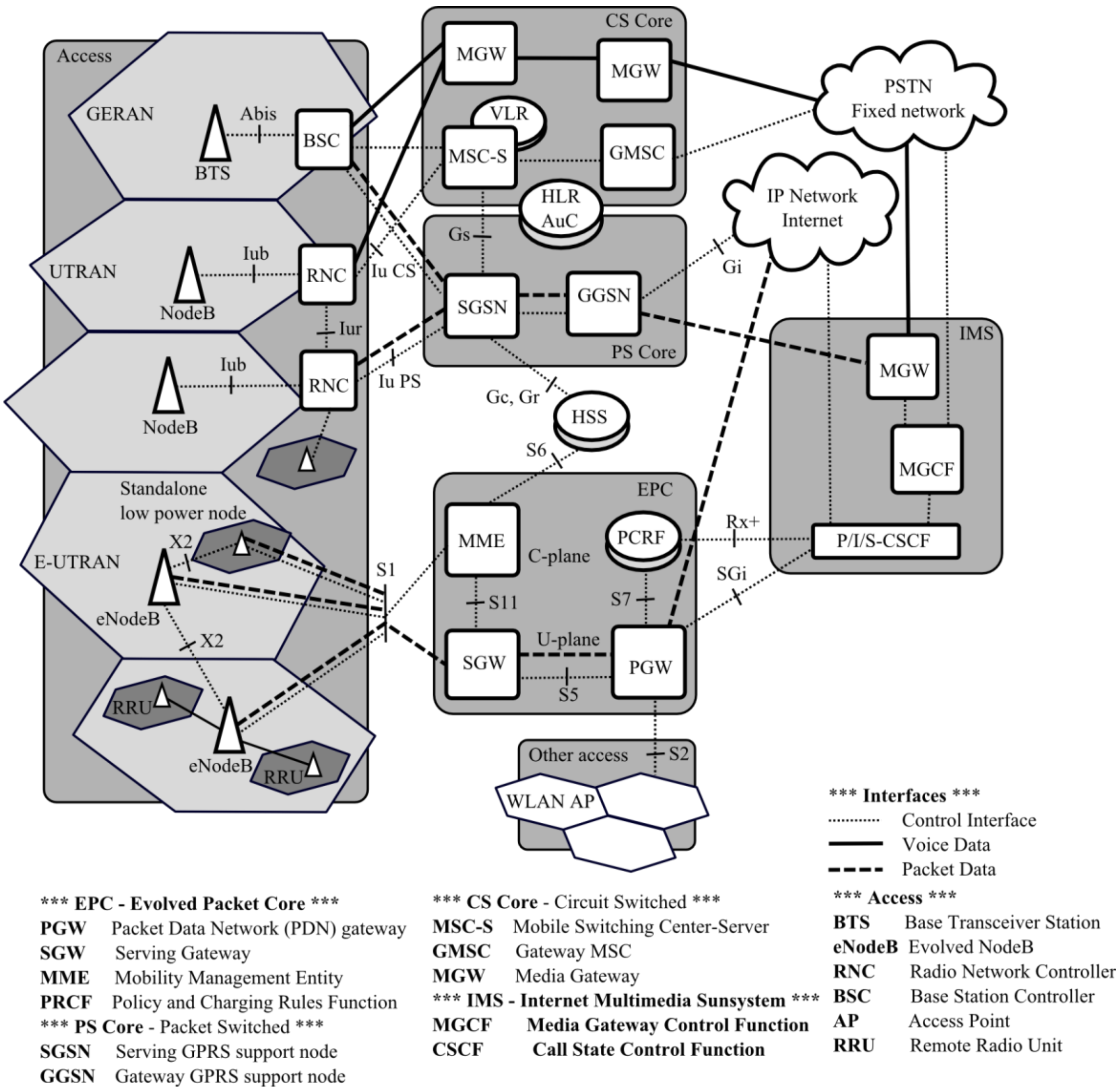

Figure 3. Heterogeneous telecommunications architecture.

Capacity improvements that will satisfy user needs could be just half, or even less when fulfilled by the use of new spectrum resources and advanced LTE technology (Marshall, 2012). Because of that (Landstrom et al., 2011), three different expansion strategies that could be implemented to meet increasing demands for data rates of upcoming mobile broadband services are presented. The expansion strategies are based on: (i) improving macro layer bandwidth with newer access technologies, (ii) densifying HSPA/LTE multi-standard macro cellular networks based on inter-site distance (ISD) reductions, and (iii) complementing the macro layer with low power nodes or creating a heterogeneous network. The results obtained for each of the mentioned expansion strategies are shown in Figure 2 (Landstrom et al., 2011).

Improving the macro layer by upgrading radio access to new technologies, such as HSPA or LTE, brings higher user data rates and improved capacity. However, further improvements could be completed through the addition of more spectrum bandwidth (Figure 2). The main advantage of the expansion through such improvements is that there is no need for new sites. According to Figure 2, densifying the macro layer is the next logical step to improving network capacity. In cases when network performance does not depend on traffic location, the number of macro sites can still be relatively low. Establishing a heterogeneous network, or complementing the macro layer with low power nodes, is a broadly accepted expansion strategy dedicated to huge improvements in network capacity. In this case, very high capacity and data rates can be achieved in proximity to low power nodes, and future capacity demands could be met by combining all three approaches. How these approaches are

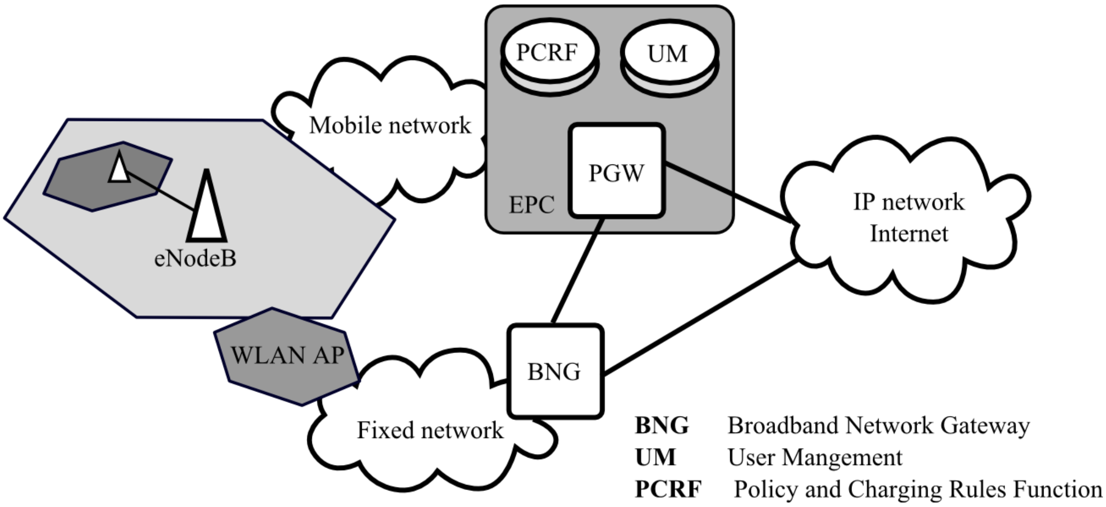

Figure 4. WLAN integration in 4G networks.

combined depends on network baseline, user demands, technical feasibility and business justification.

The heterogeneous network (hetnet) presented in Figure 3 shows it to be a complex mobile network with different Radio Access Technologies (RAT), including Wireless Local Area Networks (WLANs) and a mixture of macro cells with micro, pico, and femto cells of low power nodes. Such nodes that provide capacity enlargement in areas with higher traffic density could have different air interfaces.

While implementation of 2G and 3G small cell BSs can be found in practice, for longer periods the frequently used air interface are through WLAN access points (APs). In order to improve user experience, WLAN APs should be fully integrated in current wide area wireless access networks. This means offering seamless roaming, smart radio access type selection, carrier-grade scalability, and manageability among all integrated wireless access technologies. An integration approach, based on cooperation between the Broadband Forum and 3rd Generation Partnership Project (3GPP) Evolved Packet Core (EPC) architectures, is depicted in Figure 4.

In the proposed architecture, WLAN solutions need to implement packet-core integration and a local breakout of services through a Broadband Network Gateway (BNG). Traffic can be routed using the Packet Data Network Gateway (PGW) as part of the mobile network. Such connection with mobile edge provides mobile services to subscribers using WLAN. Common policy control and user management are essential in offering WLAN as an extension of mobile broadband solutions (Lundstrom, 2011). As an effort that contributes to the improvement of user experience, full integration of WLAN access in hetnets demands resolving the following issues (Rayment, 2012):

- shifting control from end users to network operators,
- choosing the right network, and
- managing session mobility in order to provide an uninterrupted IP service while end users change radio access technologies.

Since there are some unsolved issues and open challenges for accomplishing full WLAN integration, recent development activities focused on the use of low power nodes in the form of LTE micro, pico, and femto cells that are tightly integrated with the macro network. The micro, pico and femto cells could be attributed as site, business and residential cells, respectively. Again, as with WLAN APs, proper integration of the low power nodes is a demanding and challenging task. However, integration is important as it provides for a seamless operation handoffs for Voice over IP (VoIP) and

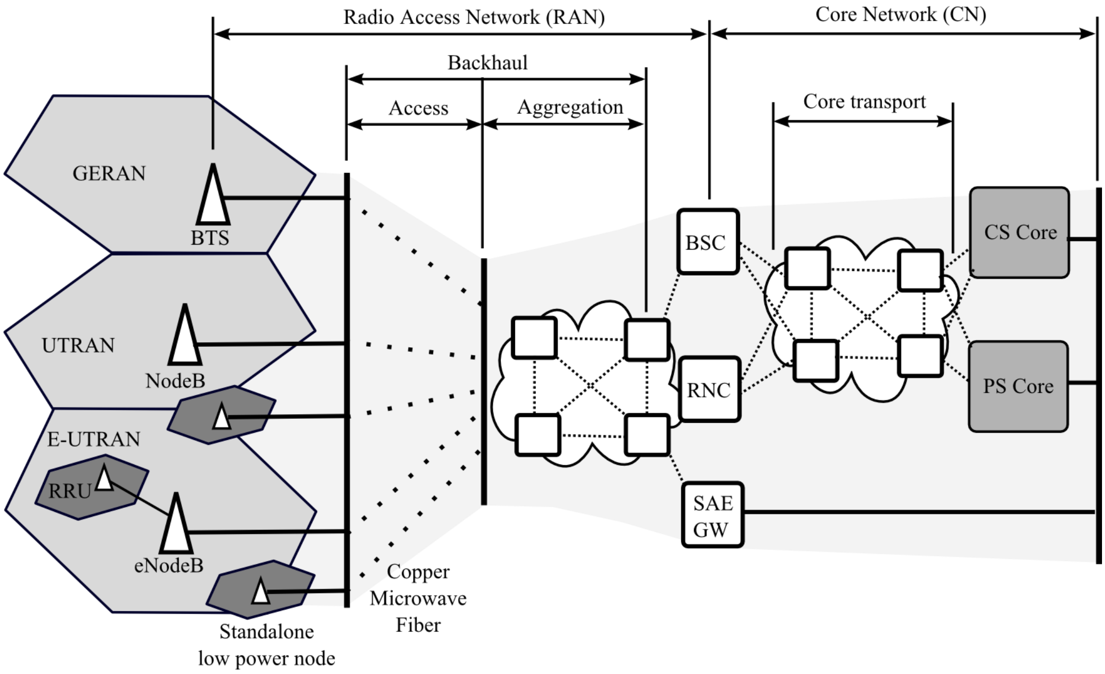

Figure 5. Mobile broadband backhaul overview.

Voice over LTE (VoLTE) calls between small and macro cells. Consequently, optimized integration will allow small cells to unload macro cells and absorb substantial traffic (Drucker, 2012).

There are two basic types of low power nodes: Remote Radio Units (RRUs) and standalone low power base stations. The choice of low power nodes depends on backhaul support—the link connection between low power nodes and the rest of the network. Different mobile broadband backhaul architectures can be seen in Figure 5. By itself, backhaul transmission constitutes a notable share of the total cost of ownership, especially as the number of nodes increases, and may have different latency and capacity characteristics. In cases where networks' backhaul has low latency and high capacity characteristics, RRUs are preferred. The RRU comprises a frequency processing unit and antenna for sending/receiving radio transmissions. Several RRUs are connected to a central control unit that collects their baseband signals and performs the signal as well as higher layer processing. A bidirectional fiber optical backhaul link is suitable for RRU deployment, and such solutions are being increasingly used in LTE high capacity networks (Landstrom, 2011). In cases where backhaul support demands somewhat lower capacity characteristics, a standalone small cell base station can be connected to the Radio Network Controller (RNC) for 3G/HSPA, or the core network for 4G/LTE (Figure 5). Hence, with the proliferation of low power nodes in hetnets, the backhaul network becomes important, either from an OPEX/CAPEX point of view or from a power consumption and energy costs point of view.

The greatest challenge of heterogeneous network deployment is its impact on overall network spectrum efficiency. The main problem is that radio frequency (RF) interference from small cells could significantly reduce the capacity of overlying macro cells and cancel initial capacity gains (Drucker, 2012). The success of heterogeneous mobile networks depends on management tools that will solve interference and other challenges such as handoffs between macro layers and small cells. The solution could be in the SON concept to provide necessary automation and management functionalities, including (Marshall, 2012):

- enhanced inter-cell interference coordination (e-ICIC),
- real time parameter optimization,
- cell load balancing, and
- multi-radio optimization technologies.

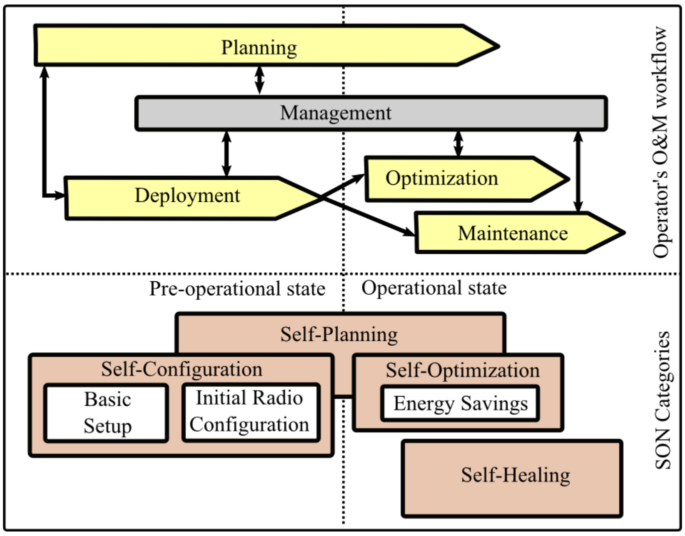

Figure 6. SON categories.

These functionalities must also contribute to the improvement of hetnets' energy efficiency through adaptation of hetnet power consumption to space and time traffic variations.

SELF-OPTIMIZING NETWORKS

The concept of Self Organizing Networks (SON) is envisioned as a key technology for assisting mobile operators to address challenges associated with the operation and management (OAM) of their radio access network (RAN). Emergence of the SON paradigm is caused by the significant increase in complexity and heterogeneity of wireless service provider networks (NSN, 2009). It is expected that this trend will continue in upcoming years and will additionally increase the complexity of operational tasks, such as planning, deployment, configuration, integration, commissioning, and the management of network elements (NEs). Many radio NEs and associated parameters are manually configured in today's wireless access networks. Besides the fact that existing manual processes are potentially error-prone and time consuming, different specialized experts must be engaged in order to perform operational tasks. These result in long delays in updating values in response to fast changes of network topologies and operating conditions, which further leads to sub-optimal network performance and increased OPEX (4G Americas, 2011).

The SON concept describes a mobile network in which the tasks of deployment, configuration, and Operations, Administration and Maintenance (OAM), are largely automated. The main aims of SON implementation are threefold and can be summarized as reducing OPEX, improving user experience, and improving network performance. An intelligent network with quick and autonomous self-optimization ability can improve user experience by optimizing the network more rapidly and mitigating outages as they occur. Network performance, in turn, is about simplifying and accelerating rollout, as well as running, maintaining and optimizing the network more autonomously and more effectively. Implementation of SON will enable more cost-effective installations, commissioning and OAM support of operators' RAN that will yield long-term savings. SON comprises a set of different manifestations addressed as self-x categories of techniques and functions, such as self-configuration, self-optimization, self-planning and self-healing (4G Americas, 2011; Bogenfeld, 2008; Feng, 2008). Figure 6 presents a typical operator O&M process and related SON categories (NGMN, 2008; 3GPP TS 36.300, 2013).

Self-configuration is defined as the process where newly deployed nodes (BSs) are configured by automatic installation procedures to establish the necessary basic configuration for system operation, including dynamic host configuration parameters (DHCP), node authentication, gateway association, and software upgrades. This process is performed in a preoperational state, which is defined as the state where the RF interface is not active. After this phase, the node shall have a minimal level of connectivity towards the rest of the cellular network, enabling additional configuration parameters and software updates to reach full operational state. Among the additional configuration parameters are radio configuration parameters (Figure 6). Obtaining initial radio configuration parameters could be considered as a particular situation of the self-configuration mechanism. It comprises the processes were radio parameters are assigned to a newly deployed network node. Parameters in the scope of initial radio configuration are: neighbor list configuration, coverage/capacity configuration through Tx power values of UE and enhanced NodeBs (eNBs), handover (HO) parameters, trigger levels, and so on.

Self-optimization is the network auto-tuning process performed according to the BS and UE measurements and overall network performance measurements. The tuning actions through changing the parameters or thresholds must result with neighbor list optimization, and coverage and capacity optimization. Self-optimization provides specific benefits in terms of minimization of operational effort, and an increase of quality and performance. Processes related to self-optimization are performed in a fully operational state that corresponds to the active BS RF interfaces (Figure 6).

Self-planning's main goal is to reduce manual pre-planning. Thus, a planning tool will deliver basic parameters such as location, number of sectors, and other high level cell parameters. The self-planning functionality through self-configuration of the initial parameters and the tuning of parameters during a self-optimization process will provide the remaining parameters automatically (Figure 6).

Self-healing is related to detecting problems and mitigating or solving these problems in order to reduce maintenance costs or avoid influence on users. The self-healing functionality includes the monitoring of fault alarms (Figure 6). In cases of appearance of alarm(s) which could be solved automatically, appropriate recovery actions to solve the fault will be triggered after deeper analysis based on gathering more necessary correlated information (e.g. measurements and testing results). This is similar to approach in De Florio, 2000. Hence, this SON self-healing feature comprises a set of key functions designed to cope with major service outages, including detection, route cause analyses, and outage mitigation mechanisms.

SON STANDARDIZATION AND USE CASES

In 2006, a group of operators gathered at the Next Generation Mobile Networks (NGMN) alliance and signed off SON as a key design principle for the NGMN, being instrumental in driving its development (NGMN, 2006). Since the first adopted specification in 2008, the NGMN alliance provides guidance to the technical standards being developed for the LTE, indicating the key use cases that are most important for carriers' everyday operations (NGMN, 2008). For that reason, the SON has received particular attention in the 3GPP as the main standardization body for LTE technology. SON features have become one of the key components of LTE networks. 3GPP included SON concepts in the LTE Evolved-Universal Terrestrial RAN (E-UTRAN) standards when 3GPP Release 8 was published in 2008 (3GPP Release 8, 2008). After that, the scope to considering SON features has expanded in subsequent releases (3GPP Release 9, 2009; 3GPP Release 10, 2011).

The ability to support SON functionalities in multi-vendor network environments was a key goal of 3GPP standardization. In particular, 3GPP standardization dedicates significant effort to define the adequate management interfaces which enable the exchange of common information used by the specific SON algorithm. Since SON specifications are developed in accordance with existing 3GPP

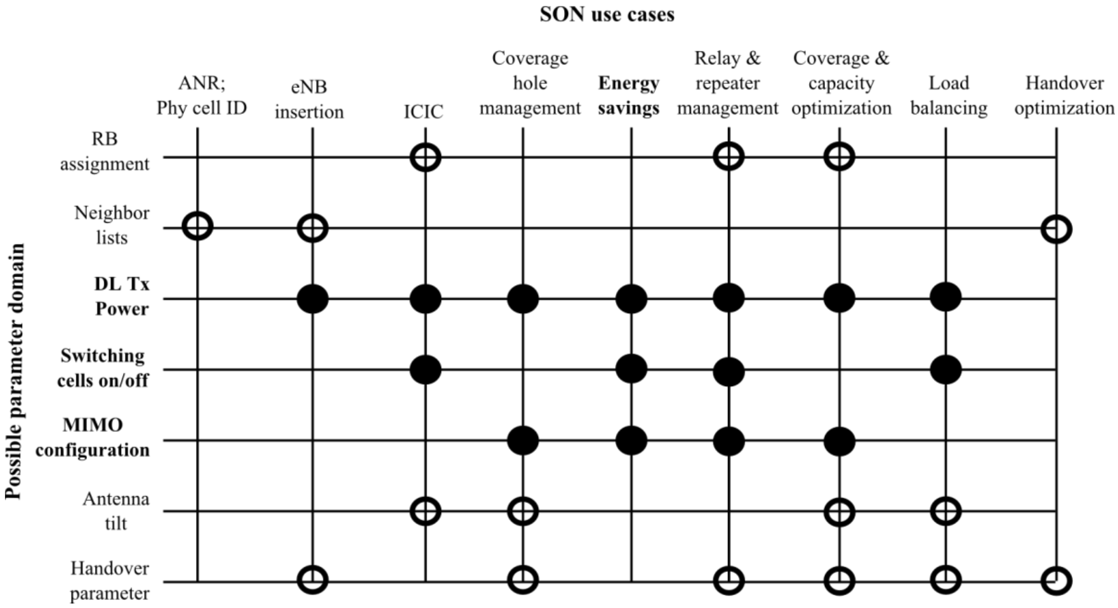

Figure 7. SON use cases and potential influence on various parameters.

network management architecture, interfaces are being defined in a generic manner to enable enough space for innovation on different vendor implementations.

Besides interface specifications, a set of the LTE SON use cases and related SON functions have been defined by 3GPP. Regarding the SON use cases considered in Release 8, focus was on procedures dedicated to initial equipment deployment and integration to support commercial installation of the first LTE networks. The SON use cases included in Release 8 are: automatic software download, automatic neighbor relation (ANR), automatic physical (phy) cell ID assignment, and automatic inventory.

The subsequent Release 9 takes into account SON use cases focused on operational aspects of already deployed commercial networks, which are related to network optimization procedures. Hence, in Release 9 enhancements to existing SON use cases and definitions of new use cases were dedicated to the: load balancing optimization, random access channel (RACH) optimization, inter-cell interference coordination (ICIC), and mobility robustness/hand over (HO) optimization.

SON standardization is continued with amendments standardized in Release 10, which offer a broader suite of SON use cases for macro and metro networks overlaid on, and interoperating with, already deployed cellular networks. Release 10's standardization scope included the following additional use cases: enhanced ICIC, coverage and capacity optimization, self-healing functions, cell outage detection and compensation, minimization of drive testing, and energy savings. The SON use cases and potential parameters on which they influence are presented in Figure 7.

Aspects related with SON are a work in progress and will be further standardized in upcoming releases of the 3GPP (Release 11, 2012) and beyond as an essential part of LTE standardization. In order to contribute to a "greener" network environment, from the 3GPP Release 10 SON will offer advanced energy saving features (these are discussed in the next section).

ENERGY SAVINGS USE CASE

As indicated in the previous subsection, Release 10 ratifies energy savings as an important SON use case. Through energy saving mechanisms, operators can reduce OPEX and provide quality services

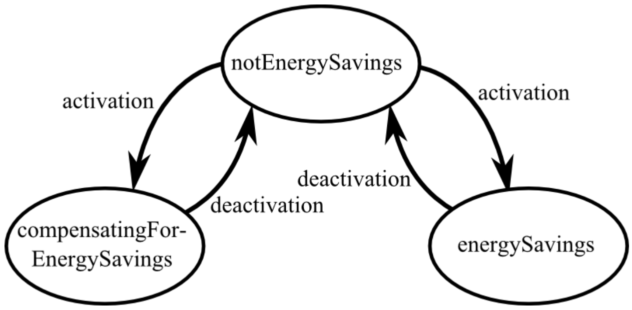

Figure 8. Energy saving states and transitions

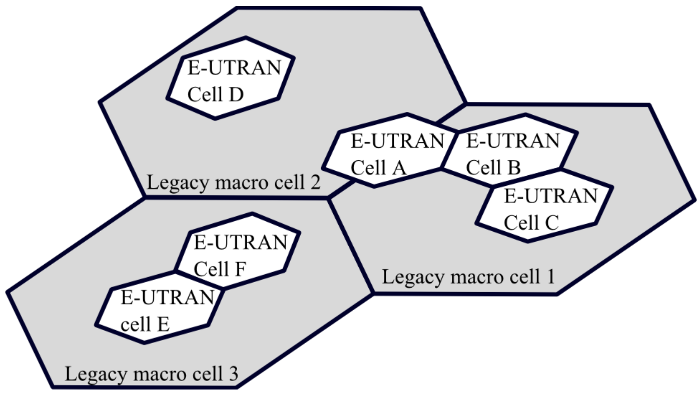

Figure 9. Cell layouts of different RAN technologies in contemporary cellular networks.

to end users on environmental friendly bases. Identifying automated energy savings management features is the goal of the technical work in 3GPP energy saving management. In addition, 3GPP also addresses the role of measurements in the form of selecting existing and new measurements to estimate the impact and effect of energy saving actions. 3GPP has defined considerations for legacy (GSM, UMTS) and new (LTE) terminals which must be satisfied in cases of implementing energy saving techniques (4G Americas, 2011). They mandate guaranteed users accessibility when a cell transfers to energy saving mode. Also, the ability to provide energy savings must exist in cases of serving a number of legacy UTs by network deployments, based on Release 10 or later. In addition, energy saving solutions should not impact the physical layer and should not negatively influence power consumption of UTs.

The basic premise of 3GPP energy savings use case is that energy expenses could be reduced if the capacity offered by the network matches traffic demand at any time/place combination. As the fundament for further research and standardization, inter-RAT energy saving is considered by 3GPP as a solution for energy saving in the E-UTRAN. According to Figure 7, the main mechanisms to save energy are cell on/off switching, adapting the downlink (DL) Tx power, and the multiple input multiple output (MIMO) antenna schemas. Possible states and transition of network elements with respect to energy saving are shown in Figure 8 (3GPP TS 32.551, 2011).

Although the on/off activity changes of NBs (BSs) introduces a new scale of dynamicity for the network and UE, those changes should not lead to degradation of QoS or network inefficiencies. Such mechanisms contribute to an increase of signaling overhead, which can potentially endanger network stability; thus, proper handling of such occurrences in the network must be considered.

There are a number of ways to include the different tuning approaches and algorithms on how these mechanisms could be deployed with other SON mechanisms. However, development of the SON

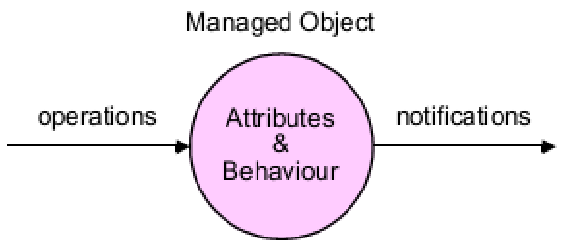

Figure 10. A managed object.

energy saving mechanism is based on the current implementation state of a mobile network. Accordingly, it is assumed that a LTE network (E-UTRAN) is deployed as an overlay to existing legacy networks (GSM/UMTS), contributing to the total capacity enhancements of operators' cellular networks (Figure 9). On the other hand, legacy networks such as GSM/EDGE RAN (GERAN) and UMTS terrestrial RAN (UTRAN) provide basic coverage and network connectivity for legacy UTs. In order to obtain energy savings, interaction between the E-UTRAN and UTRAN/GERAN systems must be accomplished on the network level.

SON ENERGY SAVINGS ARCHITECTURE

SON functionalities in the telecommunications network should be appropriately implemented and supported by a network management framework. The introduction of additional or separate platform for hosting of the SON functions is not likely due to significant impact on the CAPEX and the total cost of running the mobile network. Major efforts will focus around adapting and improving existing network management systems.

NETWORK MANAGEMENT SYSTEMS

Current network management system (NMS) functionalities typically reside outside the network on dedicated management servers. The management nodes interact with NEs through network protocols in order to execute management tasks. A prominent mobile NMS framework is the Telecommunication Management Network (TMN) defined by ITU-T (M.3010, 2000). It is a separate NMS that interfaces a managed telecommunications network at different points. The TMN has strong relations with the open system interconnection (OSI) management system (Pras, 1999). OSI management defines five functional areas in order to categorize different requirements. These functional areas are:

- Fault management;
- Configuration management;
- Accounting management;
- Performance management;
- Security management.

These functional areas comprise management functions provided by corresponding mechanisms. The OSI management is also known as the FCAPS model, abbreviated from the first letters of its functional model. The TMN's information model is based on managed objects. The managed objects structure the management information and represent a resource that can be managed (Figure 10). The set of managed objects in a system constitutes a system's conceptual repository of management information, namely the Managed Information Base (MIB).

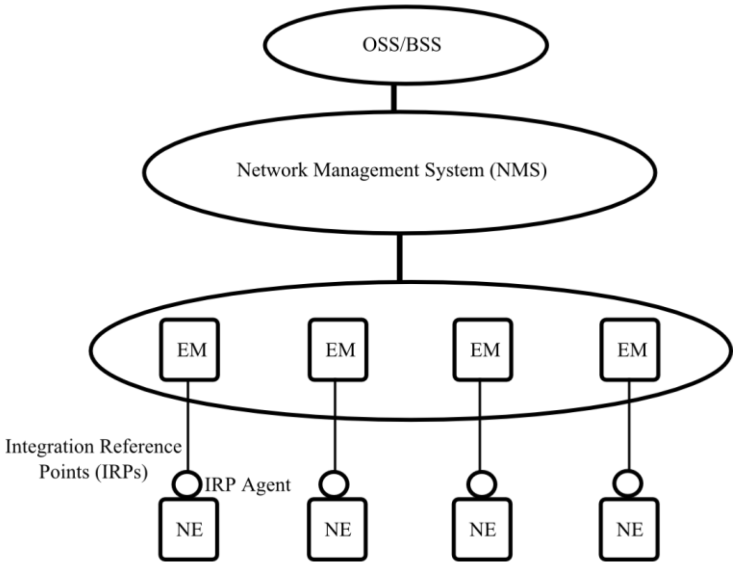

Figure 11. OAM architecture overview.

The TMN also brings a logical reference model for partitioning the management functionality according to different responsibilities. The management functionality with its associated information can be broken down into several logical layers to tackle the complexity of management.

The common logical layers are:

- element management layer,
- network management layer,
- service management layer, and
- business management layer.

While the TMN is mostly oriented to telecommunication networks in their classical sense, other important network management concepts come from the Internet. Practically, Internet management is based on these standards:

- structure of management information (SMI) (RFC2578, McCloghrie, 1999),
- management information base (MIB) (RFC1156, McCloghrie, 1999), and
- simple network management protocol (SNMP) (RFC1157, Case 1990).

The term SNMP relates to the protocol, but it is also (correctly) used for the whole Internet management framework.
The TMN is self-contained, rounded, complex and quite an abstract framework, while the Internet management or SNMP framework is simpler and provides concrete specifications with a number of implementations. While TMN divides network management into four logical levels: element, network, service and business, Internet management comprises just of the network and element levels. Internet management has been in accordance with Internet origins, providing packet transport in a highly distributed and federative network environment, but without some kind of service management.

The general OAM architecture of a telecommunications network is depicted in Figure 11. Network operators running heterogeneous networks with different RATs, complex architecture, and different equipment vendors invest considerable efforts in applying their service and business policies to the network and Element Management (EM) system of the different network domains. NEs in different domains such as mobile, transmission, packet or fixed telephone networks are connected with corresponding EM systems through Integration Reference Points (IRPs). Recent operators' demands have been focused on the integration of information from different EM systems into a centralized Network Operating Center (NOC). This enables the transformation of NMSs from network oriented to service oriented management systems.

ENERGY SAVINGS MANAGEMENT ARCHITECTURE

3GPP specifications help cellular mobile networks to identify three different energy saving management approaches based on SON architectures (3GPP TS 32.551, 2011):

- Centralized energy savings (ES) solution, where ES algorithms are executed in the OAM system. There are two variants:
    - (i) Network Management where energy saving algorithms are executed at the Network Management level.
    - (ii) Element Management where energy saving algorithms are executed at the Element Management level.
- Distributed ES solution, where energy saving algorithms are executed at the Network Element level.

Besides the centralized and distributed architecture, there is also a hybrid architecture where part of the algorithms are executed in the OAM system, while others are executed in the network's elements (Feng, 2008; Nokia 2009; 4G Americas, 2011).

In case of *centralized architecture*, cells or eNBs (namely BSs) on/off switching is performed by the centralized OAM system based on RAN information, such as load information. Energy saving algorithms reside on the EMS or a separate SON network management server (NMS) that manages eNBs activity, Tx power, and MIMO antenna selection. On a periodic basis or when needed, some specific parameters and signaling information are passed to the eNBs as the output of the SON energy saving algorithms. Such a centralized approach allows for more manageable implementation of the SON algorithms, which is the main advantage of such an approach. The disadvantage of such an approach can be found in higher latency, since key performance indicators (KPIs) and UE measurement information must be forwarded to a centralized location for processing. Additionally, the centralized SON server presents a single point of failure and an outage in the centralized NMS could result in a loss of parameters or in aged parameters being used at the eNB.

Distributed architecture is based on autonomous tuning of eNBs on/off activity or radio parameters at the RAN node, according to a certain policy configured by OAM. An example policy can be powering off the cell at 02:00 and powering it on again at 06:00. Hence, in distributed architecture SON algorithms reside within the eNBs. Such algorithms enable autonomous decision making at the eNBs. These decisions are based on information from other eNBs received via the X2 interface and UE measurements received on the eNBs. For each decision, intra-RAT (LTE) and inter-RAT (GSM or UMTS BS) neighbor nodes (BSs) should be informed, either by the OAM or through signaling. The main advantage of such a distributed architecture is through the easier deployment in multi-vendor networks. In addition, optimization can be performed much faster due to less frequently updated SON parameters at the eNBs, in comparison with that in a centralized architecture. On the other hand, ensuring standard and equal algorithm implementation in a multi-vendor network is hardly possible. As a main drawback, this imposes continuous and precise monitoring of KPIs in order to minimize possible network instabilities and to ensure overall optimal operation.

Hybrid architecture is characterized with the activation of energy saving mechanisms (cell on/off switching, Tx power adaptation, and MIMO antenna scheduling) based on signaling among RATs. In a hybrid approach, part of the SON optimization algorithm can be executed in the eNB, while

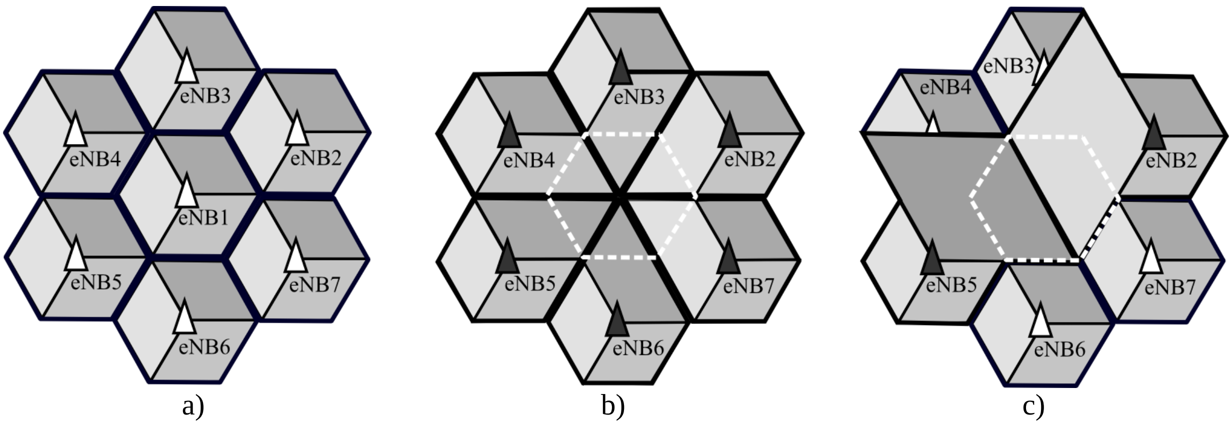

Figure 12. SON energy savings mechanism based on adapting Tx power of neighbor BSs in cases when: a) all BSs are active, b) six neighbor BSs adapt Tx parameters, and c) two neighbor BSs adapt Tx parameters.

another part of that algorithm could be carried out in the NMS. For example, shutting down a cell may be performed autonomously according to cell information available in the eNB, while cell powering on may be performed by the request of NMS or a neighbor inter-RAT nodes. In either case, intra-RAT and inter-RAT neighbor nodes should be informed after an on/off decision is made. Although the hybrid approach can reduce parameter distribution latency and signaling overheads, in practical implementations it is not without some drawbacks. In particular, practical deployment requests are synchronized with algorithms, which must be simultaneously executed on a different NE.

Ericsson currently supports a SON power savings use case for LTE and GSM technologies based on a centralized, network element level approach. It also provides a RAN power save feature, again centralized at network or OSS level. The Ericsson RAN power save feature provides energy savings by powering down cells during no or low traffic periods. The OSS can remotely, according to a schedule defined by an operator, power down cells, radio units or sites. Additionally, a strict schedule is enhanced by the traffic sensitivity function. Traffic sensitivity checks for actual traffic levels below the threshold in addition to the time schedule, and will power up cells when congestion occurs in neighboring cells. Potentially, 100 W-600 W of instantaneous power per LTE cell could be saved depending on radio BS type.

Since each architecture has its own advantages and disadvantages, the choice of architecture and corresponding energy saving algorithms is currently the main research topic of industry and academia (Samdanis, 2012; Hossain, 2012). Independently of selected architecture, shutting down a single cell or complete BS (eNB) for the purpose of energy savings will firstly require a handover of all UTs served by that EUTRAN cell, or BS, to the legacy UTRAN/GERAN BSs. Depending on instantaneous total traffic, this procedure should be followed with an increment in Tx power of neighbor BS(s) in certain directions, as presented in Figure 12.

A reversal process will take place when some powered off cell or BS is powered on again. For facilitating this power adjustment, eNBs should be equipped with multiple sets of power controlled antennas. Each set of MIMO antennas is directed to a particular sector and provides coverage for a fraction of a switched off eNB cell. Such an approach with MIMO antennas provides the flexibility to adjust the Tx power to the required directions of what can limit inter-cell interference (Figure 12b and c). Through the application of such mechanisms, energy savings defined in the SON concept represent the most promising approach to reaching significant reductions of operator OPEX.

CONCLUSION

In this paper, adaptive and resilient solutions for energy savings of mobile access networks have been discussed. The problem of energy consumption in mobile cellular networks is explained with emphasis on the BSs as the major power consumers. In addition, we present the concept of heterogeneous networks based on deploying different RATs as a mixture of: macro 2G/3G/4G cells, micro/pico/femto LTE cells, and WLAN cells. Such heterogeneous networks must be adaptive to space and time variations of traffic in order to provide optimal coverage and capacity, with minimal energy consumption. As a promising approach which can lead to truly adaptive and resilient mobile networks, the concept of SON is presented. It is shown that the 3GPP SON concept has launched a new, more autonomous network management approach based on self-x techniques and functions such as self-configuration, self-optimization, self-planning, and self-healing. In the frame of the SON concept, we show that energy savings are based on adaptive node on/off switching, Tx power scaling, and that MIMO antenna selection constitutes a prominent use case. In the paper, three different energy saving management approaches, based on the SON centralized, decentralized and hybrid architectures, have been introduced. It is shown that operators can choose the most suitable architecture depending upon current infrastructure deployments, speed of response and processing requirements, and information availability. Our future research activity will focus on improving the energy efficiency of cellular networks through joint implementation of the SON concept with software defined networks and network virtualization.

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