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Wireless technologies for isolated rural communities in developing countries based on cellular 3G femtocell deployments

M42

Procedures for UMTS/HSPA network optimization and control

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Abstract:

This is an internal document, which tackles the identification and definition of MAC procedures for the optimization of the 3G access network. Additionally, this is an intermediate document towards deliverable D42 (April 2014) and will feed the activities in WP6 (6A1 and 6A2).
The document contains a description of procedures required to: a) detection of neighbours, b) frequency selection, c) Primary Scrambling code selection, d) energy savings with on-off HNBs and e) dynamic cell expansion for load balancing. In addition to describe the work to be developed, we provide preliminary results in terms energy savings thanks to switch on/off HNB, that allow us to reduce the initial devised OPEX of the network because we can consider batteries and solar cells panels with smaller constraints.

Keyword list: dynamic cell expansion, on/off HNBs, Frequency selection, Primary Scrambling code selection, detection of new neighbours

Document Revision History

DATE	ISSUE	AUTHOR	SUMMARY OF MAIN CHANGES
10th Sep 2013	a	UPC	Proposal of a preliminary ToC
15th Sep 2013	b	UPC	Refinement of ToC
3rd Oct 2013	c	UPC, URJC	Incorporation of contributions from UPC and URJC
5th Dec 2013	d	UPC, URJC, IPA	Update contributions of UPC and URJC and incorporation of contributions from IPA
18th Dec 2013	e	UPC, URJC	Incorporation of reviews from the Technical Coordinator
21st Dec 2013	f	UPC	Final review

Schedule work plan for D42

DATE	DESCRIPTION
24th Jan 2014	Phone Call for discussing the current status of activities of 4A2
7th Feb. 2014	Call for new contributions for D42 (the initial draft is provided by M42)
14th Feb. 2014	UPC generates the first version of D42. Phone Call for review the status of the deliverable.
14th Mar. 2014	Second call for contributions
21st Mar. 2014	UPC generates the second version of D42 Phone Call for review the status of the deliverable
15th April 2014	Last call for new contributions
30th April 2014	Final version of D42

Executive Summary

This is an intermediate document towards the elaboration of deliverable D42 which the main objective is to describe the techniques to be analysed in the activity 4A2 of TUCAN3G project. The investigated techniques will tackle the self-monitoring and self-optimisation of HNB-based 3G networks in the long-term and the following topics will be investigated:

- Detection of new neighbours
- Frequency selection
- Primary Scrambling Code selection
- Energy savings with on/off HNBs and
- Dynamic cell expansion for load balancing

In all cases distributed solutions will be adopted. From the implementation platform point of view, the platform considered in WP6 is expected to have a solution implemented with on/off HNBs taking into account the 3G standard and the limitations imposed by the IP.access' equipment.

DISCLAIMER

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List of abbreviations & symbols

AICH	Acquisition Indicator Channel
AWGN	Additive White Gaussian Noise
CDMA	Code Division Multiple Access
eNB	Evolved Node B
ECM	EPS Connection Management
E-UTRAN	Evolved UMTS Terrestrial Radio Access Network
EPS	Evolved Packet System
HNB	Home Node B
LTE	Long Term Evolution
MDT	Minimization Drive Tests
NOS	Network Orchestration System (IP.access)
NP	Non Polynomial
PLMN	Public Land Mobile Network
PSC	Primary scrambling code
P-CPICH	Primary Common Pilot Channel
QoS	Quality of Service
RACH	Random Access Channel
RAT	Radio Access Technology
RRC	Radio Resource Control
SINR	Signal to Interference and Noise Ratio
SON	Self-Organising Networks
TNL	Transport Network Layer
UE	User Equipment

1 INTRODUCTION

TUCAN3G project aims to provide a sustainable 3G network for rural communities where mobile operators would like to provide service with little infrastructure deployment and little operational support. This project considers the possibility of providing 3G service by using femtocells, also refered as Home Node B (HNB) in 3G-based standards or Home evolved Node B (HeNB) in LTE-A-based standards. Recently, the term ‘Small Cell’ has been adopted to generalize the concept to base stations of different capacity and transmitted power.

The rural scenario requires the definition of network optimization procedures enabling the quick unsupervised connection of new HNBs, featuring Self-Organising Networks (SON) capabilities and low power consumption, without disregarding the provision of service satisfying the QoS requirements identified in [TUCAN3G-WP2].

Likewise, the restricted access to energy sources implies reconsideration of network procedures like automatic transmission power adjustment, adaptive femto-UE association and HNB activation/deactivation under service quality constraints. For instance, femtos should be automatically switched off whenever the traffic load is low, and should not be turned on unless required by new UE demands. Network monitoring mechanisms will be defined to control the level of service under this regime of operation.

To those ends, activity 4A2 plans to design methods for

- distributed self-organized frequency planning,
- Primary Scrambling Code (PSC) selection,
- building of neighbour list,
- coverage monitoring through on/off HNBs and
- dynamic cell expansion for load balancing.

The schemes will be obtained as solutions of rigorously formulated optimization problems which take into consideration the operating conditions and the system requirements. This activity will produce deliverable D42.

Results will be forwarded to WP6 for a study of integration into the platform.

1.1 Objectives

- Propose distributed non-supervised methods for network monitoring and optimization under energy consumption and service constraints. The monitoring is assumed to be carried out in a long term, i.e. time-scale of minutes or hours.
- Evaluate them in a consistent scenario and traffic conditions.
- Identify those proposed techniques that could be considered for implementation in the platform of TUCAN3G with IP.access’s equipment

1.2 Organization

The present document is organised in three main sections. Section 2 describes the existing procedures in 3G/LTE standard supporting the SON-based techniques. It also reviews the capabilities supported by the products of IP.access. On the other hand, section 3 presents a description of the techniques to be investigated in TUCAN3G for general rural networks. Finally, section 4 will provide a summary of the techniques that could be considered in the implementation platform addressed by WP6.

2 MAC PROCEDURES FOR 3G/LTE ACCESS NETWORKS

Self-Organising Networks (SON) is a concept that pursues the autonomous network resource adaptation with dynamic traffic adjustments [Aliu13]. There are 9 categories where self-organising procedures should be designed:

1. Coverage and capacity optimisation
2. Energy saving
3. Interference reduction
4. Automated configuration of physical cell identity
5. Mobility robustness optimisation
6. Mobility load balancing optimisation
7. Random access channel (RACH) optimisation
8. Automatic neighbour relation function
9. Inter-cell interference coordination

In [TS36300] two concepts are defined to support the concepts of self-configuration and self-optimisation:

- *Self-configuration process* is defined as the process where newly deployed nodes are configured by automatic installation procedures to get the necessary basic configuration for system operation. This process is carried out when an eNB is powered up and has backbone connectivity until the RF transmitter is switched on.
- *Self-optimization process* is defined as the process where UE and eNB measurements and performance measurements are used to auto-tune the network. This process is carried out in operational state, i.e. when the RF interface is additionally switch on.

It is assumed that UE shall support measurements and procedures which can be used for self-configuration and self-optimisation of the E-UTRAN system. Additionally, the network should be able to configure the measurements and the reporting for self-optimisation. In the following sections we provide an overview of existing SON procedures in standards and the ones considered for ip.access's products. Let us also note that although the project addresses a general 3G-based network, initially, we are interested to know what SON procedures are contemplated by the industry. In this concept, it is possible that some interesting features are defined only for LTE-based networks, but not in 3G. One example of this aspect is the X2 interface, described in the following.

2.1 *Overview of existing procedures in standards*

In section 20 of [TS 36300] the X2 interface is presented for LTE-based networks that connects the different eNB (evolved Node B) in a network. This a logical channel at the user-plane and control plane level. The X2 user plane (X2-UP) interface provides non-guaranteed delivery of user plane packet data units. Moreover, the X2 control plane (X2-CP) interface shall be used for common procedures between neighbour eNB. The following functions employ X2-CP:

- Intra LTE Access-System Mobility Support for UE in ECM (EPS Connection Management) CONNECTED
  - Context transfer from source eNB to target eNB
  - Control of user plane tunnels between source eNB and target eNB
  - Handover cancellation
- Load Management. The Load Indicator procedure is used to transfer interference co-ordination information between neighbouring eNBs managing intra-frequency cells.
- General X2 management and error handling functions
- Mobility failure event notification

- Energy Saving. This function allows decreasing energy consumption by enabling indication of cell activation/deactivation. There is a Cell Activation Procedure that enables an eNB to send a CELL ACTIVATION REQUEST message to a peer eNB, in order to request the re-activation of one or more cells which had been previously indicated as dormant.

The functions of load balancing and energy saving [TS 36300] are important for the techniques tackled in this work.

The objective of *load balancing* is to distribute cell load evenly among cells or to transfer part of the traffic from congested cells, which is performed by means of self-optimisation parameters or handover actions. The load reporting is performed by exchanging cell specific load information between eNBs over the X2 interface (intra LTE scenario) or S1 (inter RAT scenario). The load information consists of:

- radio resource usage,
- Hardware (HW) load indicator,
- Transport Network Layer (TNL) indicator
- Capacity value (UL/DL available capacity for load balancing as percentage of total cell capacity)

The objective of *energy saving* is to reduce operational expenses due to energy costs. This solution builds upon the possibility for the eNB owning a capacity booster cell to autonomously decide to switch-off such cell to lower energy consumption (dormant state). This decision is taken based on the cell load information. The eNB may initiate handover actions in order to off-load the cell being switched off and may indicate the reason for handover with an appropriate cause value. All peer eNBs are informed by the eNB thanks to the X2 interface. All informed nodes maintain the cell configuration data, although the cell is dormant. An eNB owning the capacity booster may receive two types of messages: a) a re-activation request, and b) the minimum time before that cell have to be switched off.

On the other hand, 3G-based networks, similar mechanisms for avoiding the connection of new users, or to detect the possibility of increasing the coverage are might be by means of exploiting the information of the Random Access Channel (RACH) and Acquisition Indicator Channel (AICH) in 3G-based networks. The Random Access Channel (RACH) is typically used for signalling purposes, as can be seen in section 6.5.5 in [Holma04]. It is used for register a terminal after power-on to the network or to perform location update after moving from one location to another. A terminal must be able to decode the broadcast channel of a given cell in order to find out the available RACH sub-channels. Furthermore, a base station uses the Acquisition Indicator Channel (AICH) for indicating the reception of the RACH signature sequence. This channel is not visible to higher layers and is controlled by the base station. In case a base station might decide to not transmit the AICH, then a terminal will not be allowed to be associated to that base station.

In release 10 it is introduced the Minimization of Drive Tests (MDT) [Johansson12],[Holma11], where the objective is to get the same information obtained by the expensive drive tests, by means of the measurements reported by the user terminals. The measurements introduced are:

- Downlink (DL) and Uplink (UL) throughput measurements to assess user throughput when the radio interface is the bottleneck link
- DL and UL data volume measurements to detect traffic hotspots within a cell
- The possibility to collect information about radio link failures
- The possibility to collect information about RRC (Radio Resource Control) connection establishment failures
- Enhanced availability of detailed location information that can be associated with MDT measurements
- Enhanced collection of UL measurements to identify weak UL coverage and its cause
- Flexible anonymization level for management-based MDT

- Enhanced support for a network using multiple public land mobile network (PLMN) identities.

2.2 Overview of existing procedures in ip.access products

The ip.access system is primarily focused on self-configuration in which the HNB parameters are set whenever it powers up, and the cell has to adapt its coverage and performance to existing macro cells without creating too much interference, whilst also establishing neighbour cell lists. These procedures need to move forward to support increased adaptability to clusters of HNBs operating near each other.

Primary amongst the current self-configuration tasks are:

- Location verification in order to authorise transmission.
- Detection of neighbours
- Identification of neighbour type (Radio Access Technology, nature of cell)
- Setting of neighbour cell lists
- Setting of handover and reselection thresholds and related parameters
- Setting of P-CPICH power to determine the cell range.
- Configuration of maximum allowed uplink and downlink

In terms of self-organisation, the management system carries out a number of functions. Its primary function is to monitor the performance of the system and each HNB. This includes:

- Retrieval of Performance Management and Fault Management Logs from HNBs
- Responding to and managing any raised alarm
- Periodic, or on-demand, carrying out of Network Listen scans to check for noise levels
- Manually switching off HNBs that are attached to the system. This feature is currently primarily used for maintenance, but may evolve into greater use if energy saving techniques are developed.

The Performance Management Logs may then be subsequently analysed and processed to determine Key Performance Indicators such as call drop rate, cell availability, cell load history etc.

3 ACCESS NETWORK RESOURCE MONITORING AND ADAPTATION

3.1 Detection of new neighbours

Every 3G HNB has a Network Listen (NWL) receiver installed that can be set to scan the appropriate 2G & 3G (and potentially LTE) transmit bands and report the results to the network management system. This serves multiple functions: verifying the location of the HNB before transmission is allowed, possible frequency synchronisation with neighbours, and detection of neighbours in order to build a suitable neighbour cell list for handover and re-selection.

There are a number of additional tasks that have to be carried out in order to create the neighbour cell list. Merely detecting another cell does not mean that it is suitable for handover because its signal strength may be too low or of poor quality to be suitable for a handover. CPICH RSCP and GSM RSSI should be taken in to account. Additionally, certain details of the System Information Broadcast messages of the candidate neighbours need to be decoded in order to determine whether the cell belongs to a suitable operator and it is advantageous to determine whether the neighbour cell is a macro-cell or micro-cell in order to prioritise hand-outs and determine aspects of network topology

These results need to be conveyed to the management system for validation and approval. In addition the management system may add to, or modify the list if it has additional information – e.g. it knows from the reported HNB location that there should be another cell visible to UEs served by that cell. Depending on how self-configuration of frequency and PSCs have been carried out, the management system also needs to be able to forward any necessary details towards the management system of the macro network, in order that macro-cells can be provisioned with the appropriate details of their 3G HNBs for the purposes of handover and reselection.

However, there are some inherent limitations of the approach described: the sensitivity of a network listen receiver will limit how far it can detect, typically only signals detected beyond the cell edge and in particular, there is the possibility that a neighbour cell detectable by a UE at the cell edge will not actually be detectable by network listen techniques alone. Additionally, when NWL is active, the HNB cannot be in transmission mode (or else its transmission power would drown out the NWL receiver)

LTE had Automatic Neighbour Relation (ANR) defined at launch, in which a compliant UE can report details of neighbour cells that it has detected in sufficient detail for a radio node to configure neighbour lists and request the creation of X2 neighbours. This service was not available in 3G until the end of 3GPP Release 10, and required air interface protocol changes. Consequently UEs and network nodes with this support are not automatically available.

It should be possible to derive suitable mechanisms for existing UEs that will improve the configuration and performance of a cluster of small cells, as well as help to understand how the introduction of 3G ANR could improve the process still further.

3.2 Frequency and primary scrambling code selection

3.2.1 Frequency selection

Frequency selection is a fundamental problem in *cellular networks* [Tekinay91]. In traditional (macro legacy cell) networks, the allocation of frequencies is solved by the operator in a centralized manner. However, HNBs in small-cell networks are often deployed dynamically and may incorporate on/off (sleeping) mechanisms. As a result, the algorithms must account for this dynamic behaviour and, if possible, run in a distributed manner [Chan07]. Except for a few trivial cases, the problem of frequency allocation is NP hard [Schrijver98]. Hence, suboptimal solutions are the natural path to follow. Given the focus and particularities of TUCAN3G, the allocation of frequencies must take into account state information (traffic, batteries, network topology) as well as the remaining parameters to be optimized (PSC, transmit power, switching on/off HNBs, etc.).

Frequency selection and allocation is particularly important in the HNB-based environment (or scenarios with different types of transmitters: eNB, HNB, Pico-eNB, also known as Heterogeneous Network, HetNet) where energy saving, UE performance and cell detectability have to be taken in to account. This is because if two neighbouring cells are deployed in a co-channel situation without soft handover, it is not possible to use idle mode frequency prioritisation in order to manage the cell selection of the UE. On the other hand, there is the advantage that the UE is able to read details of neighbour cells during normal transmission and without having to retune its radio, thus saving energy. In addition, neighbour cells on the same frequency cause interference to the UE. Whilst the use of soft handover may mitigate the interference this has the significant disadvantage in the case of small cells as foreseen for TUCAN3G of reducing the capacity of the system because HNBs are typically limited to 8, 16 or 24 simultaneous users and a UE in soft handover will occupy one of those positions in each cell that is in its active set.

In the case of an adjacent frequency deployment it is possible to prioritise one frequency over another for reselection. This aspect is particularly important in the HetNet scenario because if there is no prioritisation a UE only has to look for another cell to attach when the signal quality of the current cell is too low. Consequently adjacent frequencies aid the deployment of multi-layered HetNets, at the price of additional UE battery life when the UE re-tunes its radio to monitor adjacent frequencies. Further, when a 3G UE is put in to 'compressed mode' in order to retune and read adjacent frequencies, the given time is enough to measure only a limited number of neighbours.

3.2.2 Primary Scrambling Code selection

Primary scrambling code (PSC) selection has also become a prominent problem in *CDMA networks*. The main reasons are the growing interest in small-cell deployments and partially decentralized networks [Checco12]. Indeed, the optimal selection of PSCs is listed by the 3GPP standard as one of the top 5 most important requirements for self-configuration of small cells [TR 25.967].

In traditional CDMA networks (i.e., legacy macrocells), the PSC of each NB is selected among a set of 512 codes (or 64 groups with 8 codes each). Since that is a fairly high number, PSC selection/allocation is mostly straightforward. Operators typically solve this problem off-line in a centralized manner using, for example, frequency-reuse algorithms [Perlaza12]. However, if the deployment of HNBs in a network is done dynamically and, as a result, the PSC selection (management) must be dynamic too.

Using the same centralized algorithms in a dynamic deployment requires substantial exchange of signalling as well as reconfiguration of the entire network. Alternatively, the PSC of each HNB can be selected using decentralized algorithms with little (no) signalling exchange. However, designing such decentralized algorithms may not be straightforward, especially when either the number of available PSCs is small or the number of HNBs is large. Note that the fact of the number of available PSCs being small is a very common situation as many operators are expected to reserve only a few PSCs for HNB, while keeping the remaining ones for legacy macro NB. In short, decentralized PSC code selection algorithms have to cope with the following challenges: the number of HNBs can be much larger than the number of PSCs (especially if macro NBs are present and cells are sectorized where each NB will use 3 codes), the signalling burden needs to be small, the computational complexity of the algorithm has to be limited, the topology of the network varies with time (addition of new HNBs and/or sleep mode), and the algorithm has to guarantee a small probability of close-by HNBs choosing the same PSC. 3GPP has identified this problem and has introduced two terms for this that are relevant: PSC confusion, where a third cell has two neighbours that use both the same frequency and PSC combination, and PSC collision where two neighbours use identical PSCs and frequencies. PSC confusion is a problem whenever handover is contemplated and the serving cell cannot decide between those neighbours. On the other hand, PSC collision should be avoided wherever possible. Moreover, there is a practical reason that limits the size of the number of PSCs and frequencies usable in a neighbouring cluster of cells: 3G specifications limit the number of neighbours that can be broadcast in the neighbour cell lists to 32 intra-frequency neighbours and 32 inter-frequency neighbours. This is unlikely to be a limiting factor in the case of small cells with limited immediate neighbours, but does become a problem in the case of higher power / higher layer cell with many neighbours underneath it.

With these considerations in mind, three different scenarios are relevant for TUCAN3G:

S1. *Deployments where the number of available PSCs is very high in relation of the deployed HNB in a given area*. In this case the centralized off-line solutions can be used. Each HNB will always use the same PSCs.

S2. *Deployments where the number of available PSCs is slightly smaller than the number of HNBs*. Since HNBs are expected to be (evenly) spread through the coverage area, interference between far apart HNBs is expected to be negligible, so that the only issue is to guarantee that the HNBs incorporate mechanisms to select a PSC that is not used by any of the neighbours (greedy strategy)[TR.25967]. Hence, the main challenge for this scenario is to build/acquire the list of nearby HNBs and their corresponding PSCs. Obviously, the solution for this scenario can also be used for S1.

S3. *Deployments where the number of available PSCs is much smaller than the number of HNBs.* In this case, close-by HNBs have to use the same PSC, so that interference among them can be severe. To mitigate interference, intelligent code planning techniques have to be designed and tailored for the scenario at hand. The list of nearby (active) HNBs, associated PSCs, network topology and previous HNB activity should be used as input for the algorithm. The design can be tackled either using heuristic techniques that leverage the operating conditions of the particular deployment, or under a more formal optimization framework. Both game theory [Perlaza12] and discrete optimization [Checco12] have been used to that end. Examples of costs to be minimized are the long-term probability of PSC sharing or the aggregate SINR of HNBs sharing the same PSC. Additionally, a possible particular interest of TUCAN3G is to design a PSC allocation algorithm that can be used when HNB wake up after a sleeping period. In that case, the HNB should take into account not only the active HNBs, but also the sleeping ones which eventually will wake up. Development of adaptive algorithms to learn the behaviour (e.g., on/off activity) of the nearby HNBs are also of interest for this case.

3.2.3 Proposed optimization

According to the previous explanations, frequency and PSC selections share many similarities. Both are discrete optimization problems that are typically solved off-line using similar algorithms. Hence, it is reasonable to design such algorithms simultaneously. For the scenarios considered in TUCAN3G, such algorithms should be aware of the network state and amenable to be implemented distributedly. The work in this activity will begin by analysing the impact of frequency and PSC selection in network performance (congestion and energy savings). Once the main aspects to be accounted in the design are identified, algorithms to optimize the offline frequency and PSC selections will be considered. If the performance gains are significant, the design of suboptimal distributed algorithms will also be explored.

3.3 Coverage monitoring and control

Controlling the coverage area is an important issue for SON-based networks because you could also deal with the interference reduction, inter-cell interference coordination and energy saving aspects. Therefore, the proposed methods should take into account a dynamic network configuration where base stations (femtocells, HNBs or small-cells) might change the total transmitted power, increase/decrease the coverage area or switch on/off base stations. This is a total different scenario, where conventional base stations are always switched on and the coverage area do not change over the time. In this regard our research will focus on: a) on/off HNB and b) dynamic cell expansion. The first approach will only consider network optimization based on energy-saving criterions, while the second one will look into how the coverage areas of each HNB are modified as a function of the users in the network. For instance, the number of users in the different towns studied in TUCAN3G varies between the early morning, when people leave to work outside of the town, and during afternoon, when people come back at home.

3.3.1 Quasi-fixed On/Off HNB deployment

Switching off HNBs contributes to decrease interference and, more importantly, to save energy consumption. In TUCAN3G context, the energy savings are translated in a more efficient energy dimensioning (type of batteries/solar cells) and the cost of electricity in case the HNB is connected to the power grid. Usually the energy dimensioning is devised assuming that HNBs are always active, but this is not always necessary if an on/off criterion is properly designed.

However, switching off a particular HNB affects the network topology and, hence, has an impact on all other devices. Traffic that was originally served by the HNB to be switched off HNB has to be either be transferred to nearby HNBs or dropped. Closely related problems have been investigated in the areas of Wireless Sensor Networks and Green Networks [Chiaraviglio08][Chen02]. It is interesting to understand more precisely how to determine whether it is feasible to switch a cell on or off without denying an UE coverage.

In the context of small-cells, algorithms to switch off HNBs must use both traffic and energy (battery) information as input. Network topology and link capacity must be also considered. One possible solution is to design decentralized algorithms is to allow each HNB to make its own decisions, based only on local information. A more elaborate design requires exchange of information among HNBs. An alternative to reduce the signalling burden is to leverage statistical information and learning algorithms to infer the state of faraway HNBs. The algorithms will be obtained as the solution of discrete optimization problems that optimize energy consumption and/or traffic load while adhering to flow-conservation and capacity constraints. When difficult to solve (NP hard), suitable approximations and heuristics will be used.

Another scenario where on/off solutions are interesting is in hybrid or multi-tier access networks, which are composed of different kinds of BS, each powered by a different energy source. A typical scenario corresponds to having several macro-BSs (with wide coverage areas) connected to the power grid and a set of HNBs (providing coverage to smaller areas) connected to a battery. The main benefit from having these HNBs is that, since their coverage areas overlap with macro-BSs' and even each other's, they can serve some of the traffic generated in geographical areas with a high number of subscribers in those periods of time in which the number of voice calls and data connections is high. This allows balancing the load between macro-BS's and HNBs and, consequently, improves the QoS experienced by the users since the blocking probability can be reduced significantly.

In TUCAN3G, it is expected that the HNBs are equipment whose energy source is based on solar cells and batteries. In order to have low-cost viable solutions for the deployment of the access network, these solar cells and batteries should be as small as possible to reduce the cost of the equipment, which would have a direct impact of the CAPEX.

One important characteristic of the traffic profile, both for voice and data services, is that the rate of traffic generation is not constant along the day. This characteristic could be exploited to define a strategy based on election of HNBs to be disconnected when the traffic load is low. The traffic served by disconnected HNB can be transferred to other BSs that remain connected due to overlapping coverage areas. In case those coverage areas do not overlap exactly, "dynamic cell expansion" solutions could be adopted, as will be explained in subsection 3.3.2 in this document. The main benefit associated to switching off HNBs is the substantial drop in energy consumption. According to several power consumption models (see, for example, deliverable [TUCAN3G-D41]) the power consumed by the HNB due to the mere fact of the equipment being switched-on (even without transmitting any information) is significant. Lower power consumption facilitates full recharging of the batteries, that allows to extend the battery lifetime, and also allows working with batteries with smaller capacities and smaller solar cells (and, therefore, cheaper).

In the following we describe three examples of possible scenarios that have been identified in the project. For each of these scenarios, a strategy will be developed in order to activate/deactivate HNBs under different criteria:

- **Scenario A.** This scenario is depicted in Figure 1 and it is based on a 2-tier network. The first tier is based on macro-BSs connected to the power grid, whereas the second one is composed by a set of HNBs placed generally at different locations. Each HNB is supplied with a different battery and solar cell (i.e., HNBs at different positions do not share solar cells and batteries). The HNBs have smaller coverage areas than those corresponding to the macro-BSs while these coverage areas overlap (partially). The HNBs are in charge of giving support to the macro-BSs when the traffic load is very high. In those time periods where such traffic load is low, the HNBs could be turned off. This scenario is of lower relevance to TUCAN3G.

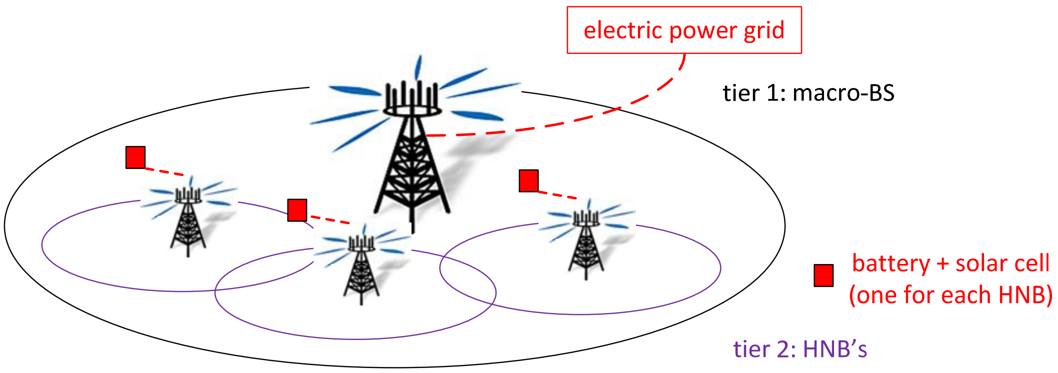

Figure 1. Scenario based on a 2-tier network. Tier 1: one macro-BS connected to the electrical power grid, tier 2: several HNBs placed generally at different locations, each one with its own battery and solar cell. The coverage areas of the HNBs overlap with the coverage area of the macro-BS.

- **Scenario B.** This scenario is presented in Figure 2 and it is based on a set of HNBs located at different positions and with partial overlapping of their coverage areas. Each HNB uses a different battery and solar cell, i.e., the energy sources are not shared among HNBs. It is assumed that HNBs serving a low number of calls can be switched off. Then, other HNBs should be kept on and expand their coverage areas (see section 3.3.2) to be able to serve those subscribers that were initially within the coverage areas of the disconnected HNBs.

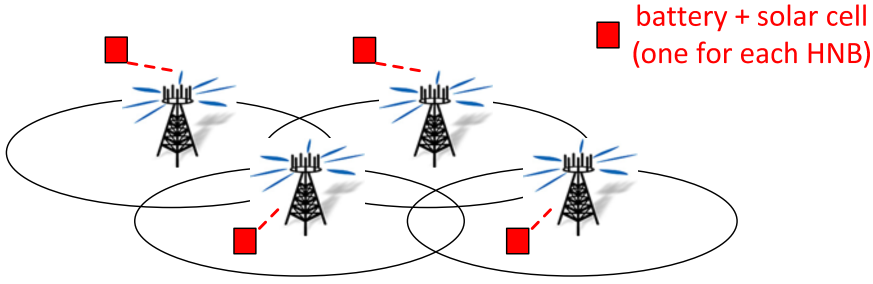

Figure 2. Scenario based on several HNBs located at different positions with partial overlapping of their coverage areas. Each HNB has its own battery and solar cell.

- **Scenario C.** This scenario is sketched in Figure 3 and it is based on a set of HNBs located at the same position with overlapping of the coverage areas. The HNBs share the same battery and solar cell. If the traffic load is sufficiently low, some of these HNBs could be switched off whereas the other HNBs that are kept providing service to all the subscribers.

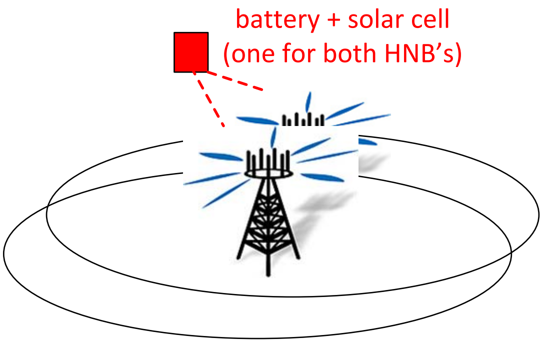

Figure 3. Scenario based on several HNBs located at the same position with overlapping of their coverage areas. All the HNBs share the same battery and solar cell.

The strategies defined to switch on/off the HNBs should take into account the following issues:

- *Blocking probability*: The users should always perceive the same QoS independently of the HNBs that are switched off, i.e., the blocking probability should always be under a given threshold related to such QoS to be perceived.
- *Analysis of the cost*: The active macro-BSs spend energy from the power-grid that has a cost associated to such energy spending. On the other hand, the HNBs are based on batteries and solar cells. The dimensioning of these elements depends on the period where HNBs have to be active, with a direct connection with it associated cost.. All this should be taken into account when developing the on/off switching strategies.
- *Traffic profile*: Obviously, the decision to switch on/off a given HNB depends on the current traffic load that usually varies along the day under a stable pattern. This means that the on/off switching strategy should also follow this pattern along the day.
- *Energy harvesting model*: Solar cell energy depends on the intensity and duration of direct sunlight along the day. A model for this energy harvesting process should be employed to characterize the process of charging the battery of the HNBs. In fact, such process should be described in a statistical way leading to parameters such as the *depletion probability*, which is the probability that a given battery gets totally discharged. When designing the on/off switching strategy, it should be guaranteed that such depletion probability remains under a given threshold.

In the literature there are some investigations dealing with the problem of switching on/off BSs for different network configurations and under different criteria. For example, in [Soh13] a strategy is developed to decrease the energy consumption by switching off BSs when the activity is low under the constraint of keeping the coverage unaltered. The strategies are developed within the framework of stochastic geometry and, therefore, are well suited for the case of having many HNBs at random positions.

In [Oh10] a strategy is presented taking into account that the traffic profile is time varying and under the objective of minimizing the energy consumption of the network assuming that there are many BSs uniformly distributed within the area of interest. [Guo12] defines different possible states for the BSs (namely normal, sleeping, expand) to develop a strategy based on that the switching between the states depends on the instant traffic load where the objective is to reduce the energy consumption and keep the same coverage. This is achieved by expanding the coverage areas of the BSs that remain activated. In the paper [Bousia12a] the authors propose a sleeping algorithm for the BSs assuming that the distances between the user equipments and their associated BSs are known (the scenario considered in that paper is defined for LTE-A). The objective of their algorithm is to reduce the energy consumption by switching off BSs during low-activity periods without sacrificing the offered QoS. [Bousia12b] addresses the same problem and approaches the solution by characterizing the power consumption statistically. A more complex problem is analysed in [Bousia13], where a scenario with several BSs from different operators are considered. This paper introduces the cost that has to be paid by an operator when its subscribers have to be served by another operator due to the fact that some BSs have been switched off. Finally, in [Saker12] a scenario with 2 tiers is considered (BSs and femtocells), where the objective is to minimize the overall energy consumption of the overall heterogeneous network while preserving the QoS. This is done by switching on/off the BSs and by modelling the traffic using Markov chains.

It is important to remark that in none of the previous referenced papers a finite energy source has been considered, i.e., in none of these works the impact of having finite capacity batteries to power the HNBs has been analysed. There are only some limited papers dealing with this case, such as [Huang13], where the energy harvesting process is formulated statistically and its impact on the network throughput is studied using tools from stochastic geometry, i.e., assuming many HNBs located at random positions with a certain density. However, note that in this paper no strategy has been presented to combine this model for the energy harvesting with the activation/deactivation of the HNBs.

3.3.1.1 Preliminary results

After having taken a look at the potential scenarios to be studied, and discussed some of the related works that can be found in the literature, in the following, we present some preliminary results obtained from a proper strategy of switching on and off HNBs.

We first investigate the scenario depicted in Figure 3. In such scenario, two HNBs are placed in the same tower and their coverage areas overlap. Thanks to this configuration, if one HNB is to be switched off then, the other may be sufficient to provide the required traffic for the whole area.

The network planning in terms of number of HNBs investigated in [TUCAN3G-D41] was derived considering the peak traffic estimation over 5 years. Furthermore, the energy dimensioning was developed assuming that the HNBs were always active. In some cases it was required two HNBs in the busy hour. However, they have not to be active during all the time, for example in some hours (mostly during night) one of the two HNBs is in fact not needed. For that reason, in this section we analyse an on/off-switching strategy in order to re-size the energy dimensioning, which could be translated into a reduction of the CAPEX costs.

The considered methodology follows the steps given below:

1) Compute the average power required by the two configurations, one HNB and two HNBs, for all possible traffic generation rates (λ 's) in a certain town.
2) Obtain the threshold (λ_{TH}) that minimizes the total amount of consumed power. By increasing λ, the configuration with one HNB at some point might require more power than the one with two due to the interference. It can also happen that the λ_{TH} is the maximum traffic that can be supported with only one HNB. At this latter point, we must have the two HNBs on. For the case where only one type of traffic is supported (only voice or only data), then this λ_{TH} is just a single value. In contrast, when two types of traffic are being considered, the λ_{TH} becomes a 2-dimensional region.
3) Switch off one of the two HNBs if the λ for a given hour of the day is lower than the λ_{TH}, for the specific traffic profile of the town into consideration.

Please note that, switching off a HNB implies putting the equipment in an idle state (*sleep mode*) rather than complete switch off and it is expected to be re-activated automatically whenever it is necessary. This is because we are assuming that the HNB have to be switched on at certain time in the future. In this sleeping mode, there is some electronics working; hence there is some consumed power. The power model consumption considered in the simulations is the one provided by EC-Project Earth and reported in [TUCAN3G-D41], which is as follows

$$P_{in} = \begin{cases} N_{TRX}\left(P_0 + \Delta_p P_{RF}\right) & 0 < P_{RF} \le P_{\max} \\ N_{TRX} P_{sleep} & P_{RF} = 0 \end{cases}$$

$$N_{TRX} = 2,\ P_0 = 4.8\text{W},\ \Delta_p = 8,\ P_{sleep} = 2.9\text{W} \qquad (1)$$

where the provided constants values are defined for femtocells .

In the following, we present some numerical results where only one type of traffic is supported (voice or data), and for the case where two traffics are simultaneously supported.

Single type of traffic

Let us start with an example of the computation of the λ_{TH}. Figure 4 shows the average consumed power as a function of a given traffic requirement during the first year in Negro Urco. The blue curve corresponds to the situation where only one HNB is active whereas the red one corresponds to the scenario where both HNBs are active simultaneously. According to the figure, in the case of only one HNB, λ is limited in some value as one HNB cannot provide higher traffic demands (guaranteeing a blocking probability lower than 2%). In this situation, the λ_{TH} is determined by such maximum traffic limitation.

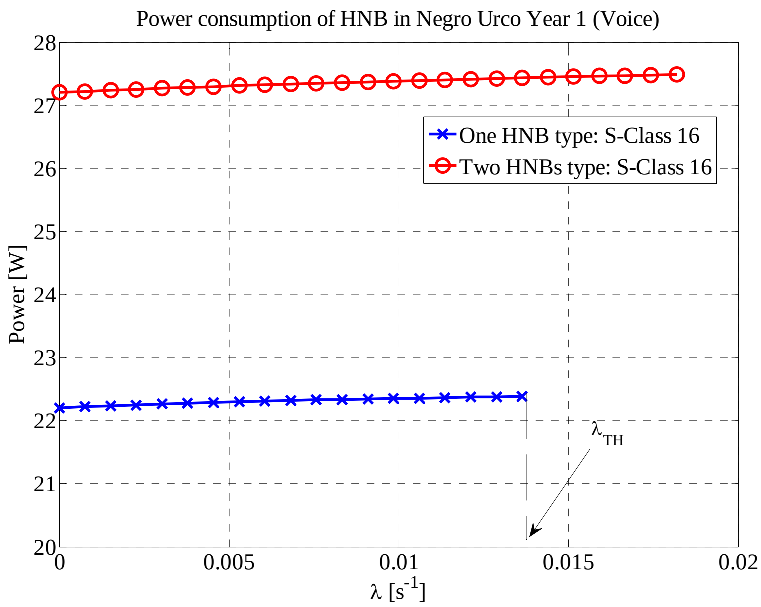

Figure 4. Computation of lambda threshold for a single type of traffic

Thus, the second HNB has to be activated to provide required traffic for the hours of the day where the traffic demands are higher than the λ_{TH} This yields to our second simulation results given in Figure 5, where we show the daily traffic profile during the first year in Santa Clotilde with λ_{TH} calculated for different types of HNBs, but the two HNBs are the same (HNB1 corresponds to S-Class 16, HNB2 corresponds to E-Class 24, and HNB3 corresponds to E-Class 24*). As it can be observed from the figure, if HNB3 is selected, the configuration with 2 HNBs is only needed in 4 hours per day (16% of the time). The remaining hours, with only one HNB active would be sufficient.

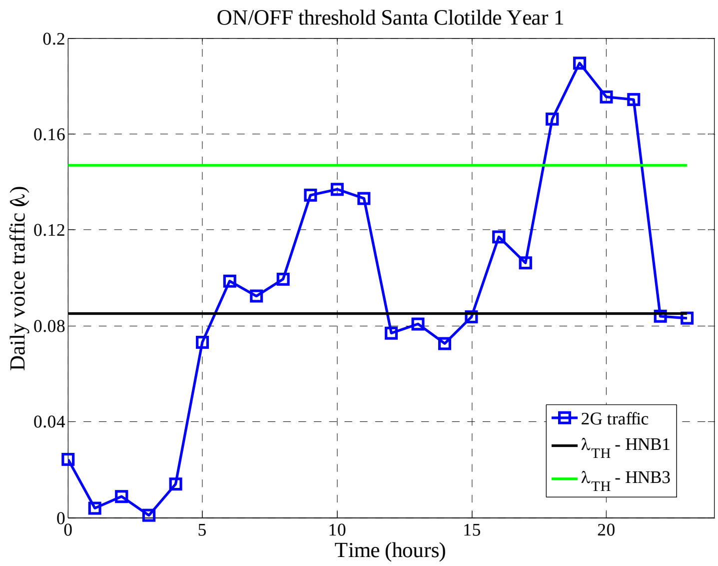

Figure 5. Daily traffic evolution with lambda threshold depicted

Once we know the λ_{TH}, we are able to set an on-off policy strategy where only two HNBs are on when necessary. Given that, we are able to compute the amount of average energy consumed by the HNBs throughout the day (considering that if a HNB is off, it still consumes some power according to the model presented in (1)). With this consumption model, we can re-size the solar panels as well as the batteries. Figure 6 depicts the reduction of the solar panel size and the consumed power in terms of reduction percentage compared to the values obtained in [TUCAN3G-D41] (where two HNBs were considered to be always active) as a function of estimated traffic evolution in 5 years, see details in [TUCAN3G-D41]. Battery size is linearly proportional to the solar panel size and, thus, the experienced reduction is the same in both cases and is not presented here. As it can be observed, for some locations (SC –Santa Clotilde, NU – Negro Urco, TP – Tuta Pisco, and SG – San Gabriel), the amount of reduction is around 15-20% for the first 5 years.

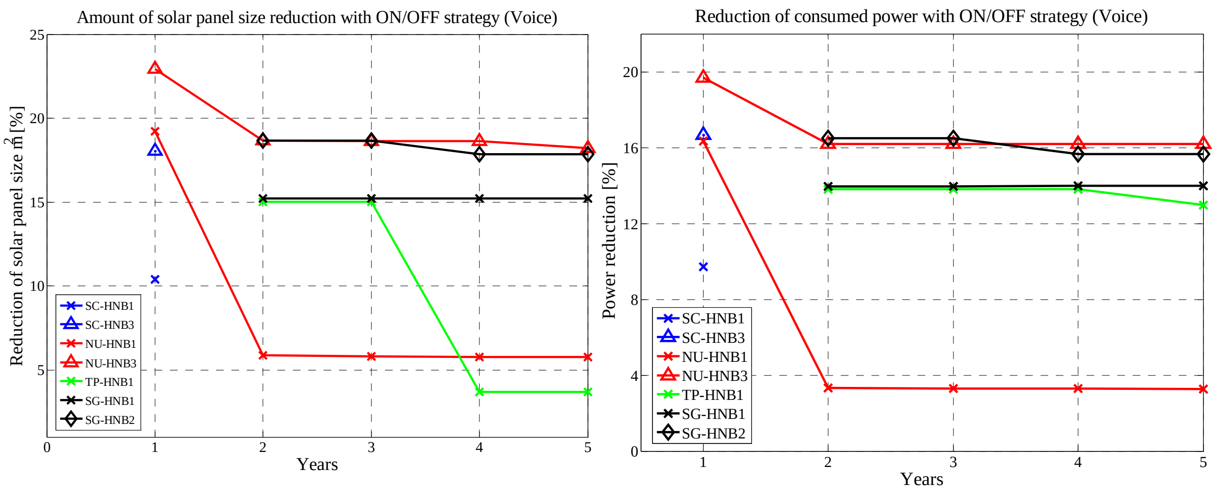

Figure 6. Left figure: amount of solar panel size reduction after on-off strategy. Right figure: amount of power reduction after on-off strategy. Results are given in percentage terms, where they are being

Two types of traffic

In this section, we consider that two different type (voice and data) of simultaneous traffic. Now, the λ_{TH} is not a single value, but a region instead. This region is depicted in Figure 7, presenting the combination of voice and data traffic generation rates that can be supported by one HNB and two HNBs simultaneously. The green region represents all the voice and data traffic generation rates that are supported using only one HNB in Negro Urco during the first year with HNB type E-Class 24*. Now the switching condition of the second HNB is not just a single value of λ, but instead are the λ's given by the frontier between the green and the red regions.

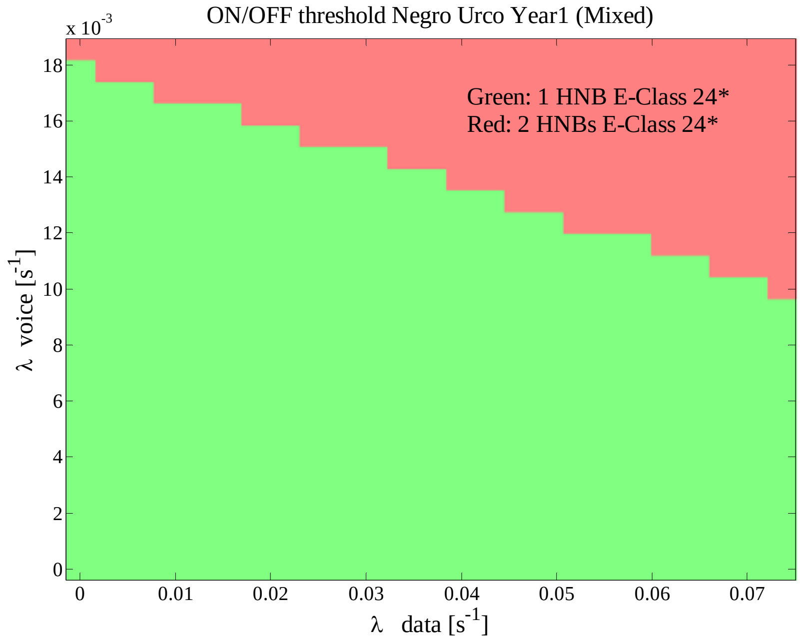

Figure 7. Computation of lambda threshold for two types of simultaneous traffic

Figure 8 depicts the daily voice and mixed traffic for Negro Urco during the first year and the corresponding configuration needed (one HNB or two HNBs) for the specific values of traffic generation rates at each particular hour of the day. As it can be seen, 2 HNBs are only needed 40% of the time (10 hours per day), while for the rest of the hours just one HNB is enough. Thus, for the dual traffic scenario, a proper on-off strategy also translates into a reduction of the total power consumed by the HNBs which directly impacts on the solar panel and battery sizes.

Finally, Figure 9 shows the amount of solar panel size in terms of reduction percentage compared to the results obtained in [TUCAN3G-D41], and the average power consumption for the case where 2 HNBs are always active and with the on-off strategy presented in this section. Results show that, during the first year, a considerably amount of panel size reduction (around 15-20%) is achieved. However, this reduction is notably decreased down to 5% as time evolves. These values strongly depend on the traffic estimations predicted for such areas in the next coming years.

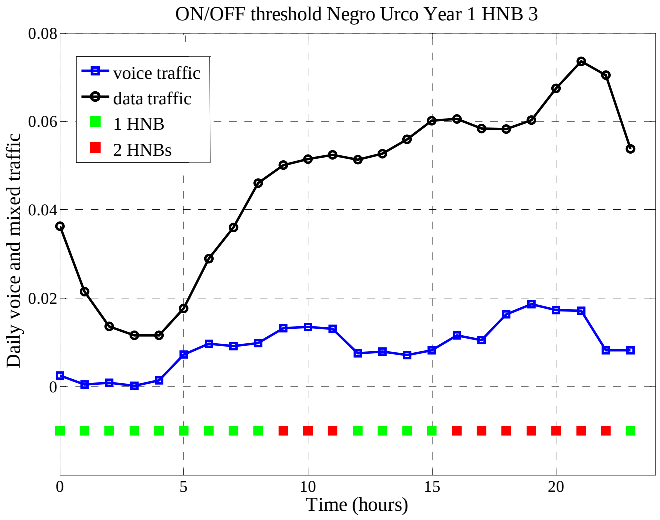

Figure 8. Daily traffic evolution and on-off strategy

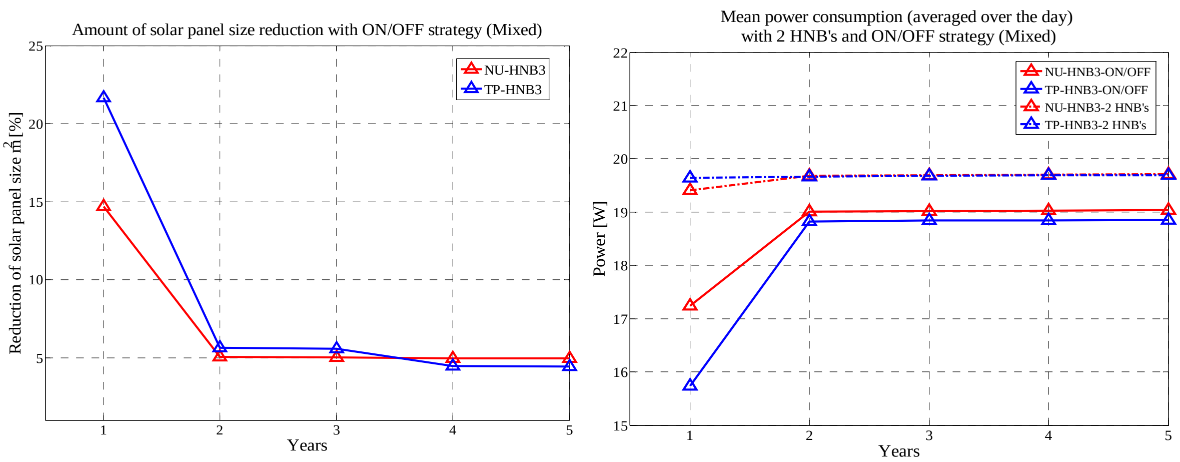

Figure 9. Left figure: amount of solar panel size reduction after on-off strategy. Right figure: amount of power consumed by scenario with 2 HNBs active and after on-off strategy

3.3.2 Dynamic cell expansion

This section will address the unsupervised coverage optimization for interference-limited wireless networks controlling and balancing the traffic load between the cells, also known as *dynamic cell expansion*. This scenario becomes relevant for rural-based networks in case of the significant demand of data traffic imposes the deployment of multiple HNBs over a given area in order to cope with the possible hot-spots, see Figure 10, where a scenario consistent with Figure 2 is shown. In case the HNBs coexist in the same carrier frequency, this scenario will be dominated by the generated interference.

Figure 10. Technical scenario for dynamic cell expansion

Radio coverage is one of the important aspects for cellular communications because mobile terminals need to clearly receive the pilot signals of the associated HNB. Coverage problems might lead to an increase of the number of dropped calls, poor voice quality or poor data throughput. Although there is a preliminary analysis about the coverage area of the network during the dimensioning phase of cellular networks, see for example [Holma04],[Laiho06], [TUCAN3G-D41], we have to control the coverage and capacity of the network as a function of the actual traffic demand, since the interference pattern varies over the time.

This topic has been investigated in [Siomina06], and [Wu13]. In [Siomina06] the power devoted for the pilot transmission (or Primary Common Pilot Channel, P-CPICH) is minimized subject to a coverage constraint by mathematical programming techniques in an environment with multiple base stations. The service area is represented by a grid of bins with certain resolution where it is assumed the same signal propagation conditions. The pilot power optimization is carried out considering in all bins (or a coverage level of 95%-98%) at least one P-CPICH from different base stations has to be decoded. The equivalent optimization problem becomes a linear-integer programming problem. Results show considerable reductions in the pilot power. On the other a heuristic algorithm for multi-sector joint beamforming in base stations to eliminate the poor coverage and minimize interference between sectors is proposed in [Wu13].

Likewise, the pilot coverage optimization and traffic load balancing are topics covered by [Valkealahti02],[Siomina04], [Ashraf10], [Guo12]. In the first reference, [Valkealahti02] it is proposed a heuristic rule for improving the load and coverage. Since adjusting the pilot power produces a larger or smaller cell, this is a way of balancing the cell load among neighbouring cells in case we can guarantee that all area has coverage. Four concepts are defined: cell load, load balance, coverage balance, and target coverage.

- The *cell load* is defined as the ratio of the total transmission power to the target transmission power, using just the downlink load.
- Moreover, the *load balance* of a cell is calculated as the difference between the average cell load and the average load in the neighbour cells divided by the standard error of the difference.
- The *coverage balance* is based on the highest E_c/I_0 (Energy per chip to total wideband noise plus interference ratio) levels that the handover-needing terminals report to the network. The coverage balance is measured as the difference of the number of reports with required E_c/I_0 level to the number expected in the case of target coverage divided by the standard error of the difference.
- The *target coverage* is the planned average proportion of reports with the required pilot E_c/I_0 level from terminals near the cell border.

If the load balance or coverage balance deviates significantly from zero, the pilot power is changed: higher than zero, the pilot power is increased; otherwise the pilot power is decreased. The interval between pilot power changes should be long enough to collect a significant number of measurements (i.e. hours).

On the other hand, pilot power is optimized by taking into account traffic intensity over the service are in [Siomina04]. They define the *capacity ratio* as the total power needed to serve all users with all types of traffic divided by the total power needed to serve the users where a base station is providing coverage. The pilot power optimization is obtained as a solution of a max-min optimization problem of the capacity ratio.

In [Ashraf10] a decentralized algorithm is analysed for a joint coverage area optimization in a scenario with a group of multiple femtocells. The heuristic algorithm updates the femtocell's pilot transmit power only balancing the cell loads among collocated femtocells and combating the coverage holes. In the scenario it is assumed that each femtocell communicates with its neighbours via the backhaul connection. The proposed approach exploits the local status information of femtocell, obtained from measurement reports of the connected mobile transceivers. There are thresholds for the maximum and minimum power devoted for the pilot transmission. The minimum value is set adaptively by the algorithm. Basically, this minimum threshold will handle the coverage holes and overlap, while load balancing is controlled by the pilot power. The main objective is to balance the load among all neighbouring femtocells.

Finally, [Guo12] designs a cellular network that can meet a dynamic range of offered traffic loads at a low energy level, where total energy consumption can be reduced 46% by extending the cell expansion. The proposed algorithm creates inner and outer cell regions, thanks to the vertical sectorization and adaptive tilting of outer cell antennas to expand and contract cell coverage. In this regard, each cell might operate in three modes: *normal* mode in which the cell maximizes the throughput of users in its traditional area, *contract/sleep* mode in which the cell is switched off and its users are passed to neighbouring cells, *expand* mode in which the cell expands by tilting its outer cell antenna directionality towards the contracted cell area. The rationale of the proposed algorithm is to switch off a percentage of cells in order to reduce the energy consumption and the interference in the network. A given cell will operate in the normal mode if its own cell load is above certain threshold or the associated compensating cells have a load above another defined threshold. In case, the load of a single cell is inferior to the threshold, then a request to go into *contraction/sleep* mode is generated, which is successfully processed when none of the compensating cells are or request to go in sleep mode.

The objective of the present work is to investigate decentralized algorithms in order to carry out the dynamic cell expansion/contraction as it is depicted in Figure 11 where the traffic load of the different cells will be considered as a constraint to be fulfilled. They will be evaluated in conditions consistent with the specifications in D21.

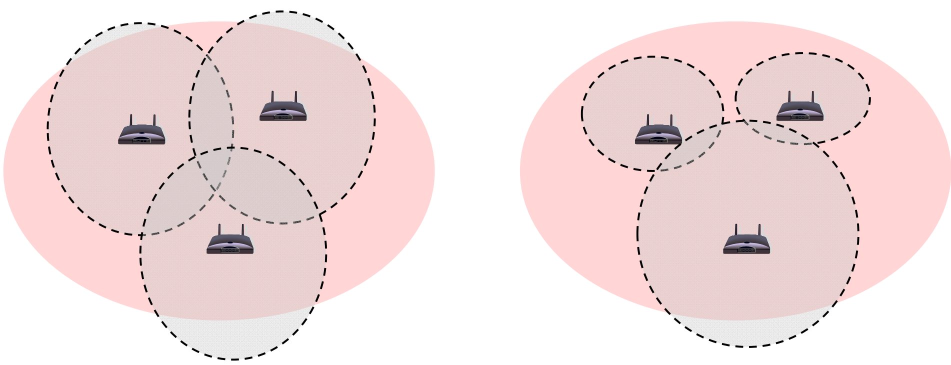

Figure 11. Dynamic cell expansion / contraction

4 PRELIMINARY RECOMMENDATIONS TOWARDS WP6

The applicability of any of the solutions investigated in this work to the implementation platform considered in WP6 of TUCAN3G is limited by the required modifications on the IP.access's equipment. At this moment, the most promising technique in terms of being supported by IP.access's equipment with small modifications is the quasi-fixed switch-on/off strategy as a function of the predicted traffic. The actual possibilities of implementation will depend on the capabilities of the NOS of predicting the current traffic and the possibility of automatize the decision. In this regard, it is expected to fulfil the following table in deliverable D4.2 as a summary of the required modifications imposed by our proposed schemes.

Technical contribution	Enhancements to 3G standard	Applicability to IP.access's equipment and WP6 platform
Detection of new neighbours		
Frequency selection		
PSC selection		
Quasi-fixed on/off HNB deployment		
Dynamic cell expansion		