COGNITIVE MULTI-MODE AND MULTI-STANDARD BASE STATIONS: ARCHITECTURE AND SYSTEM ANALYSIS

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ABSTRACT

Each wireless technology/standard has been optimized to provide a specific set of services, in accordance to technical and economic aspects. The possibility of changing the communication technology allows the introduction of more flexible management of transmitted power and radio resources in accordance to the offered traffic, services and QoS. The adoption of multi-mode base stations (BSs) offers an additional degree of freedom for efficient usage of the radio resources. One or more radio access technologies can be activated in the single cell area in accordance to offered traffic load and service requests. Users can be distributed among the different technologies. Multi-mode BSs open new and very interesting scenarios for the development and deployment of innovative mobile access networks.

In this paper we consider new access network architecture based on multi-mode BSs even including possible cooperation among different service providers. Capacity improvement due to spectrum sharing is known and shall be encouraged.

It is well known that radio access systems providing spot-like coverage can be used to off-load primary mobile radio systems extending over the entire cell area. Practical examples are provided by Wi-Fi for WCDMA and femtocells. Multi-mode BSs facilitate the implementation of the off-loading concept. Achievable improvements in the case of LTE off loading UMTS are analyzed in this paper.

1. INTRODUCTION

In the last two decades, several mobile communications standards have been developed worldwide to operate within 800 MHz up to few GHz. Each technology has been optimized to provide a specific set of services, according to technical and economic aspects. Waveforms utilized in different standard are characterized by different parameters in terms of transmitted power, occupied bandwidth per channel and Quality of Service (QoS). Multi-standard Software Defined Radio (SDR) systems allow to implement every standard on a single hardware/software platform [1] and, when SDR is combined with a cognitive engine, it allows the efficient use of available bandwidth and power by adapting the modulation scheme as a function of the offered traffic and required services [2], [3]. However, from a practical point of view, current terminals are not SDR-based and implement multi-standard transceivers by using one or more ASIC modules specifically designed and optimized for each one of the considered technologies. The possibility of changing the communication technology so to (optimally) redistribute users and services allows introducing flexible management procedures of power and spectrum resources in accordance to the offered traffic. If different technologies are classified in accordance to power, bandwidth/bit rate required for each service and QoS, they can be intelligently used to manage power and bandwidth in accordance to the number of terminals in the area and their requests in terms of services and QoS.

A flexible wireless network architecture that can meet the previous requirements can be based on multi-mode BSs able to transmit/receive signals in accordance to several wireless access standards (e.g. 2G, 3G, 4G-LTE and even Wi-Fi). The design and deployment of a radio access network (RAN) using multi-mode BSs opens new research challenges mainly oriented to identification of algorithms and techniques for self-organization/configuration, self-healing and self-optimization for the best use of radio resources available in different frequency bands (i.e. from 900 MHz up to 3 GHz). The multi mode network shall also be designed to support collaborative functionalities, mainly oriented to the (fair) spectrum sharing among the different operators.

The wireless network architecture presented in this paper is able to support the above functionalities. It is assumed that each operator has its own infrastructure and can share spectrum resources with other operators. The access network owned by each operator includes multi-mode BSs. The principle architecture of the considered integrated network infrastructure is presented and the main functionalities of its components are detailed. Some practical implementation problems are analyzed even considering the presence of legacy terminals. Practical hints for the planning and design of a cellular access network with multi-mode BSs are discussed. Some aspects related to spectrum sharing are also presented and analyzed. In particular, the advantages offered by the straightforward implementation in multi mode BSs of the off-loading concept is analyzed in the case of UMTS-WCDMA covering the entire cell area and spot coverage by UMTS-LTE.

The paper is organized as follows. In Section 2 the considered network architecture is presented. In Section 3 a discussion on the network planning and optimization issues are presented taking into account of the presence of multi-mode and collaborative BSs in the network. In Section 4 and Section 5, we analyze the cooperative dual-technology access network work and its performance, respectively, based on WCDMA and LTE in terms of gain due to the technology selection possibility respect to the capacity achievable by the WCDMA network only. Conclusions are drawn in the last Section.

2. SCENARIO AND SYSTEM ARCHITECTURE

The network architecture considered in the paper is detailed in this Section.

2.1. Multi-mode BS

In this section the main features of multi-mode BS are summarized. We consider a BS with an assigned bandwidth *B* over a variable, carrier frequency f_0. The BS can communicate with terminals in accordance to one or more radio standards such as GSM/GPRS, EDGE and UMTS including LTE. The specific communication technology to be used in *B* is not fixed a priori but can be selected by the BS in accordance to current traffic conditions and service requests. As an example the BS can decide to use a part of the bandwidth *B* to scale down to GPRS/EDGE services for each terminal in the area if the number of requests exceeds the practical capacity of UMTS. This means that the BS can allocate a portion of the bandwidth *B* to transmit GPRS/EDGE sub-carriers instead of UMTS-HSPA signals. If priority concepts are also introduced, the BS can allocate another portion of the managed bandwidth *B* to serve high priority users with UMTS-HSPA technology thus providing a higher bit rate. In Table 1 an example of service division among technologies has been reported mainly based on coverage and bit rate provided by the different techniques.

Furthermore, taking into account of the different sensitivities associated to each standard, energy efficient strategies can also be introduced. The wireless technology selection allows complying with energy and coverage requirements. In Figure 1 the coverage radii of GSM and WCDMA technologies are reported. The request of download Internet content from MS_2 and MS_3 is performed with different technologies by the users due to their position in the cell (i.e. based on the trade-off between the required bit rate and the allowable technology).

Table 1: Example of technology vs service division

Technology	Coverage	Supported bit rate	Service examples
GSM	High	Low	Voice, SMS
GPRS/EDGE	Medium/ high	Low/ medium	Email, browsing
UMTS-WCDMA	Medium	Medium	Gaming, content download
UMTS-HSPA	Low/ medium	High	Streaming
UMTS-LTE	Low/ medium	High with lower delay	Conference

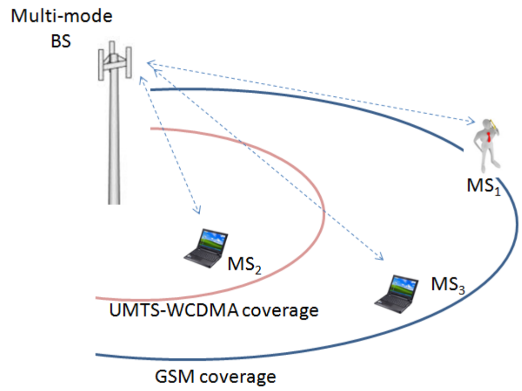

Figure 1: Coverage for different technologies.

The architecture and the main features of the considered multi-mode BS is depicted in Figure 2.

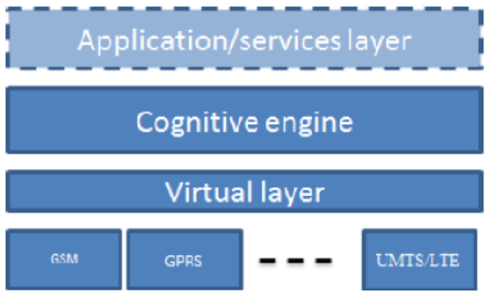

Figure 2: Architecture for the considered multi-mode cognitive BS

The multi-mode BS can receive and transmit signals according to multiple standards (e.g. GSM, GPRS, EDGE, UMTS-WCDMA, UMTS-HSPA and UMTS-LTE). To ease BS management it is necessary to introduce a virtualization layer to abstract the available wireless technologies to the cognitive/management engine [4]. This permits a simplified "description" of available spectrum resources in terms of "bit tubes" each one characterized by its availability, QoS (i.e. bit error rate, delay and jitter) and bit rate. This abstraction of PHY layer permits to simplify the description of the cognitive and management algorithms since the detailed characteristics of each one of the several PHY layers are wiped out. Cognitive/management layer sends request to the virtual layer for channel assignment having specific characteristics expressed in terms of QoS, achievable bit rate and error rate, etc… The protocol entities inside the virtual layer manage access to the radio resources taking into account for the requests of users, QoS requirements and possibly using information describing the position of the user(s) in the area, their channel quality, the power required for transmission(s), the interference situation and the congestion status of the cell. In this sense the virtualization layer can be seen as an advanced and intelligent multi-mode MAC/DLC layer managing and interfacing to several radio technologies. Starting from connection requests from higher layers, it provides radio connectivity over a multi-mode radio access scenario by proper selection of the radio technology and then channelization. Other important functions hidden inside the virtualization layer are about mobility (e.g. handover), power control, resource scheduling, adaptive modulation and coding. Similar concepts have been already presented in modern radio access networks based on the single RAN solutions presented in [5].

In order for the single BS to accommodate service requests by terminals in the cell area, BS uses parts of the bandwidth *B* to transmit signaling channels that are specific of the considered technologies. If the BS does not wish to activate one radio technology, the corresponding signaling channels are turned off. Multi-mode terminals transmit their access request using the procedures specific for the radio standard they are using for connection and whose signaling channels are transmitted by the BS. Based on received service requests over the different signaling channels, BS can assess the overall traffic load in the cell and for each terminal it can measure the propagation characteristics. Then, BS assigns the best technology to each requesting terminal so to maximize system throughput. Multi-mode BS can receive the service request on one technology selected by the terminal. However, if BS detects favorable propagation conditions and/or the service characteristics of the required service can also be satisfied by means of another and (possibly) better performing standard, the BS can "force" the terminal to select another technology. As an example, the BS can force a multi-mode terminal to use a specific technology by forbidding the use of the others i.e. by switching off signaling channels in the bandwidth *B*, and/or explicitly indicating its choice in the return paging channel. In the latter case it is implicitly assumed that protocol procedures for multi-mode terminals to communicate with the BS have been modified to include information on the radio technology to be used. The former solution based on switching off the signaling channels can be used to permit legacy terminals to interface and communicate over a multi-mode BS. As an example, if multi-mode BS receives one service request over the GSM signaling channel and channel conditions are very favorable, it can deny the request on GSM paging channel, switch off the GSM signaling carrier and switch on the UMTS carrier. In this way, the BS implicitly forces the legacy terminal to search for another technology.

2.2. Multi-mode BS in the access network

The multi-mode BSs described in the previous section can be used to create a flexible RAN. Assuming full cooperation among different operators, a first functional architecture for the considered network is depicted in Figure 3.

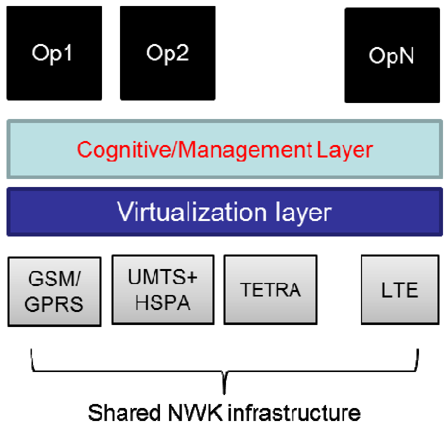

Figure 3: Functional network architecture for a full cooperative access network

To obtain the architecture in Figure 3, it has been assumed that operators share their physical infrastructures and spectrum resources (i.e. a complete cooperative scenario). Operators appear like "applications" running over the cognitive/management layer. The physical network is completely virtualized and operators contend the access to transmission resources i.e. the channels. Virtualization layer now extends over the multi-mode BSs belonging to the operator infrastructure. Contention of radio resources is mediated by the cognitive/management layer which receives the requests of services by users and operators, and it is designed to optimize the spectrum usage (at local and global level), transmission features and so on. The network architecture presented in Figure 3 may turn out to be unrealistic for many reasons. The business model for operators is not completely clear e.g. profit margin for the different operators should be identified; it is not clear who is the owner and maintainer of the physical network infrastructure; finally legal and regulatory aspects can be very complicated and very difficult to solve.

An alternative and more realistic architecture for the multi-mode access network is presented in Figure 4. Each operator owns one physical network infrastructure and exerts full control/management over it. The physical radio infrastructure of each operator is completely virtualized and cognitive/management layer implements algorithms for the (self) optimization of radio resource utilization.

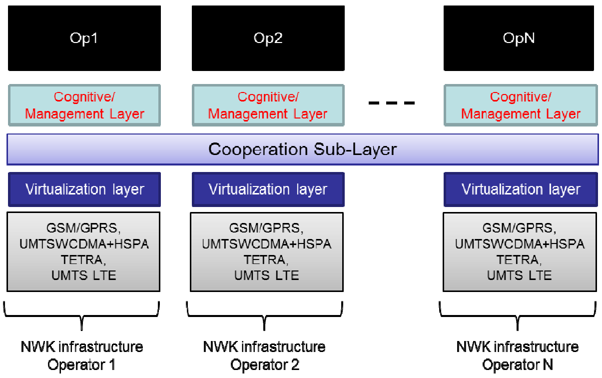

Figure 4: Considered network architecture for the cooperative multi-mode access network

In order to enable resource sharing among operators, a Cooperation sub-layer has been inserted in the network architecture of Figure 4. Protocol entities belonging to this layer reside in the network of each operator and communicate among them using intranet/Internet. Neglecting for the moment the several issues related to standardization, privacy, confidentiality, etc., the main purpose of this layer is to propagate requests for additional radio resources that can be issued by one operator to the others when its network becomes congested. Assuming that more operators cover the same area with their infrastructures (that is typical in the current practice), the request is analyzed and discussed by other operators. In the case only one operator positively responds, the price for resource borrowing has to be negotiated. In the case where more than one operator responds, other forms of negotiations/auctions can take place until one operator wins. The outcome of multiple negotiations depends on several factors such as the traffic load conditions of the networks of the different operators. Poor traffic loaded operators are more prone to borrow their resources rather than leave them unused. Obviously, operators can deny the request of resource. In general, negotiations among operators can be driven by (private) agreements. In general, algorithms for cooperation shall be designed so to guarantee an optimal usage of the spectrum resources and, at the same time, to guarantee a fair treatment for every operator; selfish operators shall be avoided since they do not permit to achieve the advantages of cooperation. For an assigned cooperation strategy, it would be of interest to study the equilibrium properties so to evidence the possible presence of dominant operators. To this aim cooperative game theory can be helpful.

As indicated in Figure 2, the cooperation layer is above the virtualization layer. This permits the adoption of a common and simplified description for the cooperation algorithms in terms of channels, QoS parameters.

3. PLANNING AND DEPLOYMENT OF MULTI-MODE ACCESS NETWORK

The design of a mobile access network with multi mode BS is a complex issue and could be organized in accordance to the following steps.

1. Network planning and initial deployment;
2. Definition of the network entry procedure;
3. Identification, description and classification of services to be supported by the network;
4. Frequency planning and band allocation;
5. Resources request and assignment. The problem of optimal resource allocation is very important and in multi-mode case the selection of technology is an additional degree of freedom to be included in the resource allocation procedures.

In the following of this section, additional details on the steps and procedures listed in the previous points are presented.

Step 1: Network design and deployment

Even though the network can be designed and deployed to be self-organizing and self-optimizing, the problem related to the initial positioning of BSs in the area needs to be addressed. For simplicity it is assumed that carrier frequency is assigned. Since multi-mode BSs are considered, to determine the distance among BSs it is necessary to select one radio technology as reference for initial network dimensioning of coverage. Technology selection can be driven by the expected offered traffic over the considered area, urban, sub-urban and rural. As an example for rural area GSM/GPRS technology can be considered for initial planning and BSs' positioning. In this case the multi-mode BSs can offer UMTS services only for users inside the coverage area that can be served by UMTS (see Figure 1). If the expected traffic is large, such as in urban areas, it may be convenient to consider WCDMA for initial planning. After initial deployment, network can gradually evolve to accommodate more traffic by adding multi-mode BSs so reducing the inter-BSs distance. Network growing can continue until all the service area can be served by a single high capacity technology such as LTE (or a newer one).

Given the initial coverage planned in accordance to a specific technology at carrier frequency f_0, if one or more BSs can adaptively change technology and carrier frequency network topology can vary with time. In particular one or more cells can increase or decrease their coverage if carrier frequency of the BSs is varied during normal operations. If necessary, to avoid cell breathing the maximum transmitter power level could self-regulated by the BSs so to guarantee the invariance of coverage extension. The addition of new BSs and the corresponding registration and insertion in the network can be managed/regulated by self-organizing algorithms.

Step 2: Network entry

To provide basic access functionalities, BSs transmit signaling channels in accordance to the reference radio technologies used for initial planning. Network entry is then carried out using the procedures specific for these technologies.

As an alternative, the technologies supported by the largest set of terminals expected in the area could be considered as candidate. BSs receiving access request also provides the cognitive/management layer with information on channel quality, terminal capabilities (e.g. supported standards), and types of service requested. As shown in the following, this information can be used not only for channel assignment but even for the (possible) radio technology swapping.

Step 3: Classification and description of communication services

In principle it is possible to distinguish between voice and data services. The characteristics of voice services in terms of QoS are well known and they are supported by every one of the considered 2G–4G technologies. Instead, data services differs for bit rate and QoS requirements. A first classification of services vs supporting radio technology is reported in the following points:

- Voice: supported by GSM+GPRS, WCDMA, LTE;
- Data – Category 1 (up to 200 kb/s with different QoS requirements): supported by GSM+GPRS, EDGE, UMTS, LTE;
- Data – Category 2 (from 200 kb/s up to 500 kb/s with different QoS requirements): supported by WCDMA, LTE;
- Data – Category 3 (more than 500 kb/s with different QoS requirements): well supported only by LTE.

Services could also be classified in accordance to the extension of the coverage they can be provided. An example is reported in the following points:

- Voice: services offered by GSM+GPRS up to 5 km (to be conservative); WCDMA: up to 1 km; LTE: up to 500 m.
- Data Cat. 1: services offered by GSM+GPRS, EDGE up to 4 km; WCDMA: up to 1 km; LTE: up to 300 m.

Classification indicated in the previous points can be used for the smart assignment of radio resources when even the selection of radio technology is accounted for. As shown in the previous points, similar services can be offered by more than one technology with the same/similar level of QoS. However some technologies may require reduced bandwidth occupancy and can serve users far from the BS without requiring an increase in transmitter power especially if carrier frequency can also be changed.

Step 4: Frequency planning and band allocation

In order to visually describe the situation of spectrum resource allocation over each carrier and for each multi-mode BS, we can consider a table indicating on the horizontal axis the carrier frequency and on the vertical the BS. An example is provided in Figure 5.

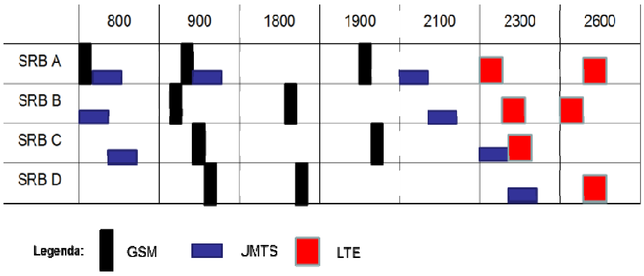

Figure 5: Example for visual representation of radio resource allocation in a multi-mode network

The width of each cell in the table is proportional to the available band around the considered carrier frequency. For each cell it is possible to draw stripes whose color indicates the radio technology and whose width is proportional to the occupied bandwidth as the example illustrated in Figure 5. The problem of radio resource optimization can be studied over a diagram similar to that in Figure 5 by finding the optimum positions of the stripes as a function of the offered traffic and of the interference constraints considered in the adjacent channel interference (ACI) parameter. The co-channel interference and ACI can be a serious concern when multi-mode BSs are considered. As an example, the proper band allocation for GSM and LTE requires to account for co-channel interference so that reuse patterns need to be introduced. In general, inter-cell interference coordination techniques [6], can be adopted. Finally, the situation of band allocation depicted in Figure 5 can change over time in accordance to the (self) spectrum optimization algorithms.

Step 5: Request for resources and admission control

As working principle the user shall be served using "the best" technology compatible with the required service and QoS requirements and guaranteeing the optimal usage of spectrum and transmission resources. Terminal contacts the network using the signaling channels of the radio technology used for initial network dimensioning i.e. the BSs transmit signaling channels for it. We assume that a user X require a data service over the WCDMA interface. The BS measures a favorable transmission channel condition and is aware user could be served (for example with an improved bit rate) using LTE technology which can adopt a higher modulation efficiency thus reducing the bandwidth occupation. Then the BS denies the access request and instructs terminal to move on LTE technology. For legacy terminals this means BS denies the request, then switches off the WCDMA signaling channel (thus forcing the terminal to search for other technologies) and switches on the LTE signaling channel. In the considered example LTE carrier has been turned on to better serve the user. Other users can directly connect to LTE if they are inside its coverage area. When the LTE carrier becomes underutilized i.e. the number of user served by LTE is small, LTE traffic can be re-directed to WCDMA and LTE carrier turned off in order to reduce energy consumption as well as to re-assign that portion of bandwidth *B* to another radio technology that, for example, can be helpful to guarantee a wider coverage than LTE.

As outlined previously, when a new carrier is turned on it is necessary to consider co-channel interference and ACI. Thus active coordination among BSs in the area is an important feature. Multi-mode BSs should be able to directly communicate. This concept has been already introduced in the LTE network [7] with the definition of the X2 interface. The X2 paves the way for the effective implementation of self organizing and self optimizing networks.

Before concluding this Section, it should be remarked that admission control (AC) is another important procedure for proper network operations. AC shall avoid overloading situations, in which QoS of other users deteriorates, [8]. In multi-mode BS networks any admission criteria shall account for the possibility of selecting the radio technology. As an example, if one WCDMA user cannot be admitted due to the high interference generated by it, BSs can instruct user to select another (active) technology in the cell, for example GPRS, to provide it with a similar service in terms of bit rate and QoS.

Another interesting application of multi-mode BSs consists in using one radio technology to off-load the technology considered for initial planning. To this aim off-load technology shall have a spot-like radio coverage. This concept has been already introduced for example in the integration of hot spot Wi-Fi and WCDMA. A WCDMA terminals detecting Wi-Fi hot-spot executes a vertical and seamless handover to hot spot technology. Multi-mode BSs permit to easily extend this concept it to any pair of technologies. As an example, starting from WCDMA as design technology, LTE can be used to off-load WCDMA when interference increases. In particular assuming LTE coverage is confined in the WCDMA cell area, the same LTE band can be re-used (when necessary) in the neighboring cells without causing harmful co-channel interference. Terminals connecting to UMTS that are inside the LTE coverage can be re-directed by the multi-mode BS to LTE thus reducing the overall WCDMA interference. The achievable performance improvement in this case will be analyzed in the next Section.

4. COOPERATION AMONG TECHNOLOGIES

Thanks to the presence of the virtualization and cooperation layers in Figure 4, telecommunication operators are able to share their spectral resources in order to maximize system capacity. Each licensed bandwidth assigned to one operator could be shared and properly used. In this paper we consider the overall bandwidth assigned to operators to UMTS-WCDMA system (e.g. at frequency 2 GHz). It is composed by $N_u = 9$ bandwidth of 5 MHz assigned to 4 telco operators. Radio mobile system is planned in order to cover the service area with this technology. We assume that operators have co-located BS according to an optimization criterion. Moreover we assume that a second technology could be deployed i.e. some WCDMA carriers could be turned off and UMTS-LTE carriers could be turned on. In this way operators can select the proper technology based on required service and coverage criteria. Generally LTE has a reduced coverage then a possible deployment between two considered technologies is reported in Figure 6 where RLTE is the radius of LTE covered cell, RWCDMA is the radius of WCDMA covered cell and DLTE is the inter-site distance between two LTE cells.

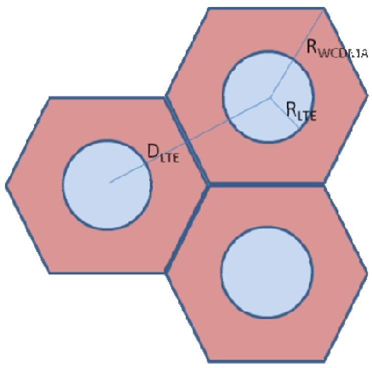

Figure 6: Implemented scenario.

According to this scenario, users can be forced to use WCDMA or LTE access in order to maximize the cell throughput i.e. according to a smart selection of the technology. The selection criterion is based on the user position. Users that are in the LTE covered area can be moved from WCDMA to LTE off loading the consumed capacity in the WCDMA system. We assume that the maximum allowable number of WCDMA user in a cell is reported in (1):

$$N_{WCDMA} = \frac{\eta_{UL}}{1+i} \cdot \left(1 + \frac{W}{R_b \cdot v \cdot \left({E_b}/{N_0}\right)_t}\right) \quad (1)$$

where η_{UL} is the load factor, i is the ratio between the other cell interference and the own cell interference, W = 3.84 Mchip/s is the WCDMA system bandwidth, R_b is the user bit rate, v is the activity factor of user transmission and $(E_b/N_0)_t$ is the energy per bit to noise spectral density ratio target for the considered service.

The number of user off loading WCDMA and moved to LTE is $\gamma \cdot N_{WCDMA}$ in the cell, where γ is the off loading factor and it is equal to the LTE area fraction respect to WCDMA area. In formulas, approximating cells as circles, it yields:

$$\gamma = \frac{R_{LTE}^2}{R_{WCDMA}^2} \quad (2)$$

The off loaded users can be replaced by the corresponding user quantity. A part of it, in particular a fraction γ of the replaced users, falls in the LTE coverage area and then it could be moved again. Then, at the second time users moved are $\gamma^2 N_{WCDMA}$. This could be reiterated until the LTE maximum capacity is reached. If it is not reached some channel remain unused in LTE system and they could be used for other users in LTE area. Note that theoretically, we have to consider the integer part of off-loading user. Nevertheless we can negligee the integer part thanks to the rate matching box in the receiver chain that allows properly adapting the transmission rates and then users.

After L iterations the number of off loaded users is:

$$N_{off} = N_{WCDMA} \sum_{l=0}^{L} \gamma^l = N_{WCDMA} \cdot \gamma \cdot \frac{1-\gamma^L}{1-\gamma} \quad (3)$$

Note that N_{off} cannot exceed the maximum allowable users of the LTE system. Then $1 \leq N_{off} \leq N_{LTE}$, where N_{LTE} is the number of allocable users in an LTE system and its value is reported in (4):

$$N_{LTE} = \frac{N_{system\_carrier}}{N_{user\_carrier}} \cdot \frac{R_{b-LTE}}{R_b} \quad (4)$$

where $N_{system\_carrier}$ is the number of subcarrier assigned to the system (e.g. for 5 MHz $N_{system\_carrier}$ is equal to 300), $N_{user\_carrier}$ is the number of subcarrier assigned to one user, R_{b-LTE} is the user bit rate and it is equal to $N_{sym} \cdot N_{bit}/1$ms with N_{sym} the number of symbol per subframe (1 ms long) and N_{bit} is the number of bit/Hz depending on modulation scheme (i.e. QPSK = 2 bit/Hz, 16QAM = 4 bit/Hz, 64QAM = 6 bit/Hz). Note that we have not considered coding and MIMO.

Considering that the modulation scheme depends on the experienced $(E_b/N_0)_t$ by the user, we can individuate three regions corresponding to QPSK, 16QAM and 64QAM modulation. Moreover increasing the modulation scheme provides greater bandwidth efficiency or allows inserting a higher number of users in the time-frequency resource grid. Then R_{b-LTE} is rearranged as in (5):

$$R_{b-LTE} = \left(3 \cdot g_{64QAM} + 2 \cdot g_{16QAM} + 1 \cdot g_{QPSK}\right) \cdot \frac{N_{sym} \cdot 2bit}{1ms} \quad (5)$$

where g_k with k={64QAM, 16 QAM, QPSK} is the fraction of covered LTE cell for 64QAM, 16 QAM and QPSK modulation scheme. If $N_{off} > N_{LTE}$, another carrier should be allocated for LTE.

5. RESULTS

The off loading capability leading to WCDMA capacity improvement is analytically evaluated in the scenario described in the previous section.

To have reuse distance equal to 1 for LTE system in Figure 6, it is necessary to evaluate the interference produced by the other cells on the reference cell. To this aim we assume to have a maximum allowable noise raise $r = (I + \eta)/\eta$ that the reference cell is able to tolerate without exceeding the bit error rate or equivalently the $(E_b/N_0)_t$. Then considering the condition for coverage we have:

$$P_{LTE} G_{TR} L_{TR} \frac{L_0}{R_{LTE}^{\delta}} = \left({E_b}/{N_0}\right)_t \eta r \quad (6)$$

And considering the condition to calculate the interference I for the reference user, we have:

$$P_{LTE} G_{TR} L_{TR} \frac{L_0}{D_{LTE}^{\delta}} = I = \eta(r-1) \quad (7)$$

where P_{LTE} is the transmitting power, G_{TR} and L_{TR} are the join antenna gains and join internal losses for transmitter and receiver, respectively, η is the thermal noise, L_0 is the minimum coupling loss and δ is propagation pathloss exponent. Combining (6) and (7), it yields:

$$\frac{L_0}{R_{LTE}^{\delta}} \cdot \frac{D_{LTE}^{\delta}}{L_0} = \left({E_b}/{N_0}\right)_t \cdot \frac{r}{r-1} \quad (8)$$

Then, considering that $D_{LTE} \cong 2 \cdot R_{WCDMA}$ and substituting (2) in (8), we obtain the maximum γ with reuse 1:

$$\gamma_M \equiv \gamma = 4 \cdot \left(1 + \left({E_b}/{N_0}\right)_t \cdot \frac{r}{r-1}\right)^{\delta/2} \quad (9)$$

We assume $(E_b/N_0)_t$ = 7 dB for QPSK, $(E_b/N_0)_t$ = 13 dB for 16QAM, $(E_b/N_0)_t$ = 19 dB for 64QAM and r=2 dB. Results for γ regions are reported in Table 2.

Table 2: Values of g for several modulation schemes and constant propagation exponents

	δ=3	δ=3.5	δ=4
$\gamma_{QPSK} \equiv \gamma$	0.5959	0.7335	0.8520
γ_{16QAM}	0.2606	0.3701	0.4778
γ_{64QAM}	0.1080	0.1770	0.2546

In the considered scenario g_k with k={64 QAM, 16 QAM, QPSK} are equal to, respectively:

$$g_{64QAM} = \frac{R_{64QAM}^2}{R_{LTE}^2} = \frac{\gamma_{64QAM}}{\gamma_{QPSK}};$$

$$g_{16QAM} = \frac{R_{16QAM}^2 - R_{64QAM}^2}{R_{LTE}^2} = \frac{\gamma_{16QAM} - \gamma_{64QAM}}{\gamma_{QPSK}};$$

$$g_{QPSK} = \frac{R_{LTE}^2 - R_{16QAM}^2}{R_{LTE}^2} = \frac{\gamma_{QPSK} - \gamma_{16QAM}}{\gamma_{QPSK}}. \qquad (10)$$

The improvement due to smart technology selection is evaluated respect to the case which the operators work in their assigned bandwidth separately.

The gain of technology selection, G_{TS}, is reported in (11):

$$G_{TS} = \left(1 - \frac{l}{N_u}\right) \cdot \left(1 + \gamma \cdot \frac{1-\gamma^L}{1-\gamma}\right) \qquad (11)$$

where l is the number of 5 MHz bandwidth assigned to LTE technology.

In Figure 7, the technology selection gain is reported as a function of different values of γ. Several values of L and l are considered as parameters.

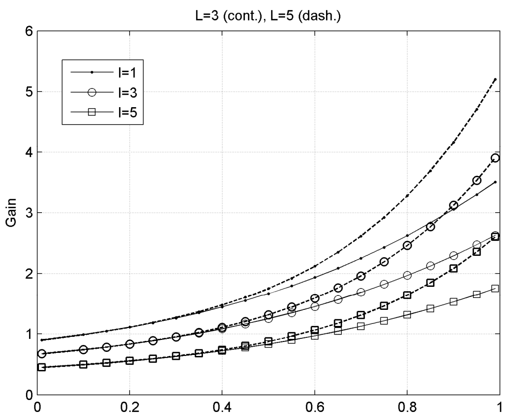

Figure 7: Gain G_{TS} vs γ values

When $G_{TS} \geq 1$, it is convenient to adopt this strategy until γ is allowed to respect the LTE reuse 1 and the number of reiteration does not exceed the maximum number allocable in LTE system (i.e. $N_{off} > N_{LTE}$).

6. CONCLUSIONS

The adoption of multi-mode BS offers an additional degree of freedom for efficient usage of the radio resources. Radio access systems providing spot-like coverage has been proposed in order to off-load primary mobile radio systems extending over the entire cell area. The proposed system architecture highlights a virtualization layer for a full cooperative access network.

Planning procedure has been described to allow the deployment of Multi-mode access network. Entry procedure has also been considered and resources request and assignment has been included in the RAN deployment.

Finally selection technology algorithm has been highlighted. Performance in terms of number of LTE users off-loading the WCDMA technology has been evaluated. The fraction g of area to be allocate to WCDMA and LTE technology in the considered scenario has been analyzed for several values of off loading iterations and number of bandwidth assigned to LTE.

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