INTER-OPERATOR FLEXIBLE SPECTRUM MANAGEMENT VS. ROAMING

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ABSTRACT

This paper illustrates the current vision on *Flexible Spectrum Management* (FSM), dimensions the technical mechanism involved in FSM from time, space, function, entity and ownership and in addition gives comprehensive comparisons with the state of the art in inter-operator spectrum resource management presented by the roaming technology. Comparisons show the attractive potentials given by FSM compared to the roaming technology and motivate the research activities towards a set a high efficient FSM solutions.

1. INTRODUCTION

Operators generally face time varying capacity demands. Under the *Conventional Spectrum Allocation* (CSA) method, operators designed and dimensioned their communications networks to cope with the "busy hour" traffic, which is the time of the peak use of the network resources. A single operator with CSA may not cope with the increasing spectrum demand. On the other hand, in the future communication systems, very broadband carriers are envisaged, an operator may only afford to obtain license for only 1-2 4G carriers. Therefore, dynamic schemes enable operators to serve high-demanding traffic would be more appropriate and also help shrink the investment risks thanks to the reduction of CAPEX.

Roaming as one of the existing inter-operator technologies can be considered as a candidate solution to solve the temporal shortage of the resource. The classical roaming, as provided by the radio network through inter-operator SLA (*service level agreement*) allows the mobile terminal free movement and reachability well beyond the coverage of single cells [1]. Among the number of roaming types, i.e., across location area roaming, national roaming and international roaming, the roaming among overlapping PLMNs distinguished by operators provide connectivity for the mobile user even when their primary operator's network is fully loaded. From the *Radio Resource Management* (RRM) viewpoint, roaming is a feature where operators *share* the spectrum resources in their individual networks through the roaming mechanisms.

The blocks of spectrum allocated to a particular *Radio Access Technology* (RAT) is often underused in certain periods in a day and in certain areas. Also, the licensing of 3G frequencies in Europe showed how expensive it can become to obtain licenses for these carriers due to competitive bidding. This implies that any operator is limited in the capacity he can provide due to cost reasons.

Analogous to this is the concept and mechanisms of inter-operator Flexible Spectrum Management (FSM), which is intensively investigated in the E2R project. FSM breaks the exclusive spectrum "ownerships" of operators and manages operators' spectrum resources jointly and dynamically through allocation, de-allocation, sharing of spectrum blocks within a single or between different radio access systems.

Viewing FSM, three basic modes can be classified: the Centralize Mode, the Distributed Mode and the Interruptible Mode. In the Centralized Mode, there is a need of a master entity, which controls the spectrum access and allocate spectrum dynamically according to the spectrum policy. Typical master entity is the meta-operator which normally presents the regulatory body. The coordination of spectrum can be carried out by setting a range of spectrum resources as a common pool (*Spectrum Pool*) allowing dynamic accesses from different operators based on pre-assigned thresholds. It can also periodically auction pieces of spectrum directly to the operators.

Different to the centralized mode, in the *Distributed Mode*, more intelligent spectrum access algorithms are distributed to intelligent terminals or communication groups. In the shared spectrum environment, radio apparatus access the spectrum more autonomously based on the previously agreed protocols. The behaviour of such spectrum accesses is very similar to public society obeying the etiquette (*Spectrum Etiquette*) that the collision and interferences resulted from common access are expected to be reduced. In order to maximize the individual benefits in terms of cost or resource occupation, game theoretic practices can be applied. For regulatory and security reasons, this mode is mostly applied in the unlicensed band.

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Another mode is named as *Interruptible Mode*. In such mode, the secondary user can access the spectrum pool from the spectrum holder, who has already purchased or rented that resource. Due to low traffic intensity, the spectrum holder allows the access from the others. Evidently, if the spectrum holder and the secondary users attempt to access the spectrum simultaneously, the former has higher priority. In most cases, the primary user broadcasts the controlling parameters, e.g., maximum allowed transmission power and access intervals to the secondary users using its own network infrastructure.

With this paper, we position our research activities through detailed comparisons between 'roaming' and FSM.

We organise the paper as follows: Section 2 gives a retrospect on State of the art technologies and views on spectrum harmonisation, where roaming is positively considered as a promising technology. In Section 3, we compare the differences between roaming and FSM conceptually from some aspects; in Section 4, we point out the significant performance difference between FSM roaming on spectrum efficiency and cost. Section 5 concludes this paper.

2. REPTROSPECT: WRC VIEWS ON ROAMING

It is commonly viewed, e.g., from the previous WRC meetings, that harmonization of spectrum has positive impacts to the success of mobile technologies towards a certain level of economies of scale. Roaming is one of the candidate solutions of harmonization. However, currently, more advanced spectrum harmonization technologies are also entered for discussions, and have been viewed as possible alternatives.

Although roaming offers virtually the 'sharing' of spectrum resources, it has by its nature a certain limitation. In the rest of the paper, we will analyse a number essential features given by FSM enabled by Reconfigurability to show additional flexibility and performance enhancement given this candidate technology vs. roaming.

3. DIMENSIONING AND COMPARISON

FSM differentiate itself from other technologies by its attributes, which help us in dimensioning FSM in order to have a concrete comparison with roaming. Attributes like ownership, mechanism, time scale, etc., are respectively studied in the following subsections.

3.1 Ownership

The ownership of a committed spectrum resource block is allocated to different operators alternatively. In an important contrast to this, roaming is based on a fixed spectrum allocation.

Dedicated ownership of roaming:

Under the roaming agreement between operator A and B, spectrum resources for A and B are exclusively assigned. In the rest of the paper, we define operator A and B are partner operators. Normally, a fixed guard band between operators and between RATs has to be standardised before the network deployment is performed, as depicted in Figure 1.

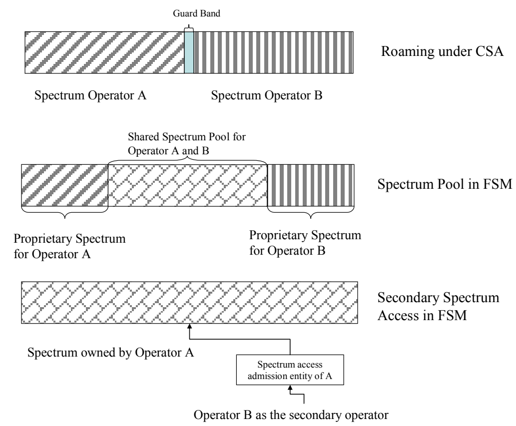

Figure 1, Ownership comparison

Shared pool in FSM:

In the centralised mode introduced in Section 1, a common pool is shared by operators. It could be a pool of spectrum resource assigned by the regulator for the involving operators. It could also be contributed by the partner operators. Under the pre-defined admission protocols, e.g., power thresholds, operators could manage their RATs freely for the subscribers. With some advanced system level control protocols, guard bands can be much reduced without losing much system performance [3].

Flexible ownership priority in FSM:

One more FSM scenario is the secondary spectrum access case under the interrupted mode. As shown in Figure 1, operator A can lend its spectrum to the secondary operator, e.g., operator B. Since A has the executive access rights to the spectrum, it can interrupt B's spectrum usage at any time.

We have classified cognitive spectrum access as the distributed mode in the area of FSM [4], this category allows logically more distributed spectrum access rights. Its ownership aspect by nature is different to roaming; we therefore compare them in Section 3.6.

3.2 Call Handling Mechanism and Involving Network Entities

FSM handles call admission at the RAN; in contrast, at the roaming scenario, the core networks belonging to both operators must be involved for the call management.

We take the mobile originated call as an example. A roaming mobile begins with an operation that initiates access to the network and informs the *Visitor Location Register* (VLR), at the same time the switching centre has to check up its available resources to the backbone network. At this

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time instance, negotiation between its own trunk request from its own users and the roaming user will take place. According to the contract, partner operator can down scale the priority of the roaming users.

Active circuit-switched calls loss their connections to the network when roaming has to be applied. In the IP based data communication case, a nomadic roaming needs the operator of the partner operator assign a new IP address to the roaming user. Normally there is no context transfer between two independent data networks, which consequently also results in a loss of connection or an establishment of a new connection. In the newly roamed network, mobile user might have to custom his perception, e.g., adapt to the push services provided by the new operator. The home operator of the roaming user automatically loses the connection, so that the push services, such as customer support services, automatic software downloads can not anymore be applied.

In case partner operators are co-located, roaming users has to search for pilot channels and listen to broadcasting common control channels. Time used for searching, synchronisation, and registration is comparably much higher than FSM, where the later one has much design freedoms from the system view point. In Section 4.1, we give a typical example on the call handling using system level radio resource management under the scenario of FSM.

3.3 Time Scale

From the time scale viewpoint, roaming is only based on the call session level. FSM functions have time resolutions varying from millisecond level to month year's level. Down to the cognitive radio as a distributed mode of FSM, the change of spectrum allocation to RAT and terminal is with the fastest speed.

Several spectrum measurement campaigns have highlighted that spectrum is not scarce, but is rather under-used or not appropriately used by the current Radio Access Technologies (RATs). The fact is that some substantial temporal traffic patterns variations have been observed for cellular voice service ([5]-[6]) and TV broadcast [7] systems. Some other measurements have outlined the existence of "white spaces" into spectrum at lower temporal resolutions (milliseconds to minutes) [8]. Spectrum occupancy measurements of all bands 30 MHz to 3000 MHz, undertaken during the Republican National Convention in New York [9], have shown that the occupancy (defined to be the average duty cycle based on the time-frequency product) varied from much less than 1% (in the 1240-1300 MHz Amateur Band) to 77% (in the 174 MHz – 216 MHz, TV Channel 7-13 Band). The overall average usage was 13% during a peak use period. With respect to this, FSM needs to provide more flexibility by applying its functions under different time scales and not only the call session level as it is applied for a Roaming. In addition to the scenario between operators, FSM also provides the possibility for a given operator to optimise its spectrum usage among RATs within its own spectrum resource.

3.4 Reconfigurability Aspects

FSM allows reconfiguration of terminals supporting different RATs of different operators or the same operator in different time. For single mode terminal, roaming is single RAT based. The connectivity under roaming given by a low end terminal with supporting less RATs protocols will be limited.

Operators running FSM may possess licenses for concurrently operating more than one RAT within the same service area. Using the committed spectrum resource, the operator is responsible to select the most appropriate RAT and to partition the traffic to those RATs, according to traffic variations, in order to maximize the efficiency of their network. Moreover, apart from the RAT selection, the reconfiguration of the terminals inside one network segment (a subnetwork) is essential.

The *Spectrum Management within a RAT* denotes that the operator considers a specific RAT. In doing so and in knowing the amount of traffic to be served within a certain area, the operator decides on the utilization of one or more frequency bands. In addition, terminals can be reconfigured to cater for the changes of the spectrum. For instance, reconfigurable terminals in the higher loaded RAT can be reconfigured to the less loaded RAT. This feature is obviously not supported by roaming.

3.5 AAA/Billing Procedure

The AAA entities at the network record all access activities in a format recognized by the wireless operator's billing, provisioning and customer care systems.

The main difference between roaming and FSM is that, under roaming a user has to indirectly buy the whole service from another operator; whereas for FSM, this operator owns at a time an amount of spectrum resource, its users can obtain the radio access through its own specified RAT. This part of spectrum needs not to be mandatory used by the same RAT. From the involving entities view point (see Section 3.2), the handling of a call is only inside the domain of the users' own operator, and the involving entities are much less than the roaming case, it gives the operator therefore sufficient room for pricing.

Assuming that a user wants to communicate and therefore his mobile phone seeks for the BS of his operator subscribed. The BS determines its load, and if there is the need for more resources, because the user states the wish of a proper service during the AAA, the BS can rent spectrum based on FSM. Thus, the additional costs are only for the spectrum, and not for the whole service. Furthermore, it is not necessary to drop the call. Moreover, assuming a loaded cell and during the service provision to the users, some of the users wish to extend this service, e.g., to get higher

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Quality of Service (QoS) or additional features, the wished capacity will result in an overload leading to reject some wishes using static spectrum management. Regarding only roaming, there are two possibilities for the users:

1. Their mobile phones are capable for registering in both operators' networks, that is the same service can be alternatively served by two RATs, e.g., over the foreign operator's network and the own network. An advanced dynamic resource management, e.g., ARMH (*Adaptive Radio Multihoming*) [12] over the two partner work is no possible due to the absence of the joint RRM entity. To support *Joint Radio Resource Management* (JRRM) between roaming networks, more signalling, synchronization and handshaking effort are needed than the one for FSM (this is not yet supported however). If the services could only be assigned in discrete portion and the user needs just a certain fraction, the efficiency, i.e., price per service, will decrease.
2. If the user terminal is single mode and not able to manage a service over more than one RAT, the user has the choice to stay in the cell and take the reduced service, to interrupt the service or to change to the foreign cell and pay the proper roaming fees. All opportunities do not enhance users' satisfaction.

For FSM, some core network function might be reallocated to the radio front, therefore resulting in a more spectrum efficient network oriented network architecture. The spectrum needs to be rented or leased at the cell level, depending on the demand. The resource market is local and a decentralized intelligent which is responsible for the customer and demand situation ensures a rapid reaction to the market. This action includes automatic negotiation for spectrum with foreign neighbourhood cells which do not necessarily belong to the same RAT category. Following the distributed approach, the price for each cell can be dynamically and locally determined, because of the different costs of the additional spectrum if needed. These costs can be redeployed to the averaged spectrum price, but dynamic in time. On the other hand, the resources can be auctioned in order to instantaneously react on the market. Both suggestions lead to a decentralized pricing and billing system.

In contrast, the roaming contracts are static, otherwise it has to take place a negotiation for each user enter a foreign cell. In turn, this would be a flexible service management taking much signalling effort because of negotiating with the user and his operator.

Recapitulating, AAA for a mobile terminal is done by its own operator. If a user roams from its own operator to another operator, it has to take and pay for both the service and spectrum provision of the extrinsic operator; whereas, by FSM the user only needs to pay solely or in average for the spectrum from the intrinsic operator.

3.6 Applicable Radio Environment

FSM is not only limited to infrastructure network as Roaming, but can also be implemented for distributed radio access case, e.g., Ad hoc network and infrastructureless network.

Current research on *Cognitive Radio* (CR) motivates intelligences in the end terminal even without the assistance from the network. This aspect is specific for FSM rather than roaming. As described in the third mode of FSM in Section 1, in the cognitive scenario, a user terminal is able to seek for spectrum to use for communication. The cognition is based on the experience, on the observation of the frequency band, on additional information and on the current situation of the CR (Figure 2). Such an intelligent entity has to be capable to scan its environment and gain information out of this collected data and finally act according the cognition. The environment in which a user terminal is located can be divided into sub-environments which can be described by specific parameters. The division into different sub-environments is useful to design and specify *Intelligent Algorithm* (IA). The input of the IAs then is the parameter set of this sub-environment. Furthermore, the output of the IA can comprise parameters of other sub-environments. For example if the sub-environments includes the spectral power density and the IA wants to improve the QoS e.g., the BER, the IA can adjust the modulation and coding scheme.

Considering an infrastructureless network in which there is no RRM entity, the network can grow in space and frequency range as long as the nodes are able to detect the occupation of a certain interval of their network. As an extension to that, other neighbour networks within the range providing sufficient coverage, can expand the network by recognizing each other through cognitive radio. The same matter could arise in frequency range, if the terminals of a network decide to increase the bandwidth in order to transmit with a higher data rate. The cognitive terminals of one network can shift their frequency range to free spectrum to grow either in space, number of participants and bandwidth. The CRs interact with each other, at least to observe the other and react according their action. Thus a set of interacting CRs can be seen as a Cognitive Network which possesses at least the same abilities.

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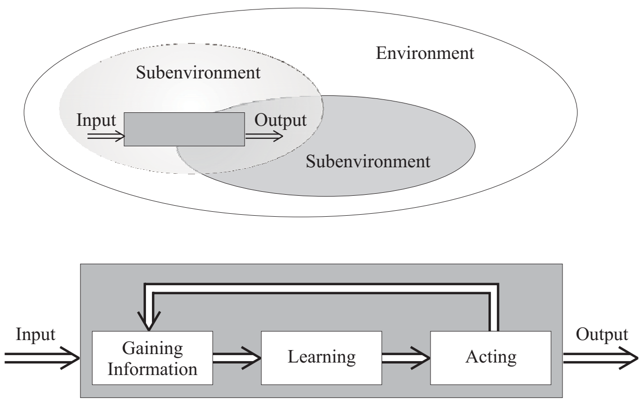

Figure 2, Cognitive Radio functionalities

4. SPECTRUM EFFICIENCY AND COST EFFICIENCY

FSM allows fast reaction of CSI (*Channel State Information*), therefore, its decision is more accurate and efficient. Roaming does not optimise trunking gain, loses the diversity gain, multiplexing gain, interference perturbation reduction gain, and of course network capacity gain.

With FSM, reconfigurable terminals are able to receive great amount radio resource instantaneously. Besides that, call dropping, call blocking rate especially during handover will also be significantly reduced. From the traffic theory, the targeting QoS performance has a monotonic relationship with the available system resource and traffic requirement, which can be simply described by $Q_T = I(R, \rho_M)$, with Q_T the QoS target, R the system resource, ρ_M the maximum affordable traffic by the system. Due to more delay time caused by roaming, dedicated spectrum resources given by CSA, low end terminals without reconfigurable capability, effective resource given by roaming will be considerable less than FSM, i.e. $R_R < R_F$, under the same QoS target, $\rho_{MR} < \rho_{MF}$, i.e. roaming offers less capacity than FSM, where subscript '$_R$', '$_F$' present roaming and FSM respectively.

The spectrum efficiency gain is achieved by pooling spectrum between different radio access technologies given intra $\sigma_{i,i}$ and inter $\sigma_{i,j}$ spectrum reuse distance constraints between base stations operating different technologies. One analysis of pooling has been recently published in [10]. For $P_{Blocking}$ = 5%, pooling scheme outperforms single system based strategies assuming non seamless roaming. Pooling scheme, FCA with channel borrowing and DCA improves respectively the number of served users of 144%, 66%, 66% compared to Simple FCA. Additional FSM gains results for some other scenarios have also been shown in [11].

From the cost viewpoint, in terms of CAPEX and OPEX, flexible spectrum requirement less time and less entity involved in the control loop, so that the network can be operated with less expenditure under sufficient spectrum efficiency target. This leaves also remarkable space for the end user billing. In the following, we introduce a non-replaceable flexible RRM scheme and an example of economical aspects penetrated to JRRM algorithm. Both can not be realised under inter-operator roaming.

4.1 Network Controlled Flexible inter Frequency Handover

As depicted in Figure 1, operators can use the proprietary band as the ground base to admit new calls, where, call admission procedure is identical to the normal call establishment procedure as specified in the individual air interfaces. In case of high load traffic in the proprietary spectrum, the operator triggers the mobile terminal to move to another spectrum band by using a beacon signal with a short period of time and constant power. The beacon signal is transmit for detecting the QoS measurement and power of the shared spectrum. If the operator receives the positive acknowledgement value from mobile terminal before the pre-set deadline is violated, inter-frequency handovers are triggered for the on going calls from the current proprietary spectrum to a shared spectrum without transmitting broadcasting information will occur. The cells without broadcasting channel is terms as '*virtual cell*'

The proprietary spectrum is used to admit new calls and capacity and QoS of the services taken place in it should be guaranteed. The shared spectrum pool is different to proprietary frequency pool, which is only used for accepting handover call, where the inter frequency handover call is defined here as the call from the proprietary spectrum to the shared spectrum.

Three key signaling-messages can be used: the *trigger message* in old RAT (proprietary band), a *beacon signal* in new spectrum and the *acknowledgement* sent from the mobile terminal to the network. The trigger message is used to inform the mobile terminal of the future existence of shared spectrum that the virtual cell is about to use. The beacon signal is used for mobile station to measure the connectivity QoS, i.e., if it is possible to establish a new link in the shared band. The acknowledgement is transmitted from the mobile station if the terminal agrees to be re-admitted (handover) to the new spectrum by informing the network about the agreement of the mobile whether the new connection can be established. In order to enter the shared spectrum, the mobile terminal must detect the beacon within a given time threshold.

The trigger message is through the old RAT, where the mobile terminal connects with the network in proprietary spectrum band. It needs to inform the terminal the band the mobile terminal should listen to and related time period. A timer value should be used in the network side before it starts to wait for the acknowledgement from the mobile. If the acknowledgement is not received in time, the handover

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attempt fails; new users/sessions should therefore be further selected.

The shared spectrum can be partially or fully applied only to admit handover calls with virtual cell usage. Most of the system information is not transmitted in the virtual cell, i.e., free resource information, base station identification number, etc. Necessary system control information such as power control command, necessary location information, synchronization information, etc. are needed. Since this method blocks new call request in the shared spectrum, the uplink capacity is therefore saved.

4.2 Economic Aspects Penetrating to JRRM

The envisaged radio resource auctioning mechanisms can be further extended and exploited in the context of heterogeneous RANs, with the proper interaction between the EM (*Economical Manager*) entity for the auction and bidding processes management and the JRRM entity for the radio interface management.

As long as JRRM involves a range of functionalities (e.g. vertical handover, scheduling through ARMH capabilities, etc.), an efficient control over the heterogeneous RATs can be assumed with advanced algorithms, which may cover different time-scales. In particular, a proper management at the shortest time-scale (e.g. milliseconds) allows fully exploitation of the theoretical capabilities that the considered scenario offers at the same time that improving the economical outcomes.

Let's consider, from a conceptual point of view, that a given RAT is able to support a certain maximum interference level for a proper QoS provisioning. Then, let assume that spontaneous traffic generation would lead to a variable interference pattern along the time given by $I(t)$. In this case, QoS would not be maintained in some periods (i.e. for those t that $I(t)>I_{max}$), while capacity would be lost for other periods of time (i.e. for those t that $I(t)<I_{max}$). The intrinsic traffic regulation provided by the auction mechanism (see Section 3.5) in coordination with JRRM organising the access to the radio segment would target to modify $I(t)$ to $I'(t)$, whose ideal pattern would be $I'(t)=I_{max}$ at any time.

5. CONCLUSIONS

FSM provides finer grained radio resource scalability and initial research shows that it significantly reduces signalling overhead and delay by reducing the core network involvement. Excitingly is the flexibility offered by FSM fully deploys Reconfigurability, which provides capacity gain and higher user QoS than the pure roaming technology. Optimal solutions combing FSM, network management, JRRM, and radio resource auction are under our investigations.

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