VERTICAL HANDOFF IN WIRELESS OVERLAPPING NETWORKS

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ABSTRACT

As wireless communications services continue increasing, continuous coverage and QoS parameters must be guaranteed to the end user. Due to the fact that in most places several wireless networks might be available, handing off between them can significantly enhance network efficiency and user satisfaction. In such a scenario, continuous environment monitoring is required for estimating links' conditions in real time from which the network selection process is executed. This paper presents a vertical handoff architecture relying on SDR capable devices for simultaneous diverse networks' parameters identification and dynamic communication link adaptation.

1. INTRODUCTION

As new applications and higher user requirements continue increasing over wireless communications systems, new interoperability mechanisms must be implemented to satisfy such conditions. Due to different network access technologies, topologies, and implementations, one network might not be able to provide continuous coverage and required QoS parameters to a mobile user during an entire session. That is why handing over between different wireless networks appears as one of the fundamental solutions in today's heterogeneous wireless systems.

The term handoff refers to the process of transferring an ongoing call or data session from one access point to another [1]. When access points using the same network technology are involved in the handover procedure it is referred to as horizontal handoff. On the other hand, vertical handoff refers to the process of transferring an ongoing communication between access points using different network technologies.

This paper is organized as follows. Section 2 presents the interoperability requirements for providing seamless vertical handoff capabilities to the end user. In Section 3, environmental awareness is described along with specific network conditions fundamental for the best network selection process. Section 4 presents the test bench utilized for evaluating a proposed algorithm in a wireless overlapping circumstance. Finally, in Section 5 conclusions are stated and future work is projected.

2. INTEROPERABILITY REQUIREMENTS

The handover procedure between different wireless networks may be user or network initiated depending on the current state of the communication links or user QoS requirements [2]. The network might decide to transfer a call to a new network for load balancing, congestion management, reduction in service delivery cost, user contract, traffic shaping, power consumption [3], radio resource management [4], service availability or spectrum licensing cost. On the other hand, a user generated handoff may be a response to channel conditions, interference, application requirements – throughput, delay, jitter, security-position within the overlay system, terminal capabilities or user-specific mobility statistics [5].

Interoperability implementations for wireless overlapping systems must take into account the following considerations for appropriately allowing the users to obtain the best possible service from the available networks:

- Network service providers must agree in the kind of interoperability services they are willing to provide to the users. Not only does this include the development of technical solutions, but also commercial agreements under which the overlay network architecture maximizes the satisfaction of both: Service providers and end users.
- Mobile terminals must have the capability of operating different wireless network technologies at the same time. This can be accomplished either by the use of several network interfaces or cognitive radio terminals based on Software Defined Radio (SDR).
- Horizontal and vertical handoff capability must be ensured for managing mobility within the overlapping system. Even though one wireless network might cover the entire area, QoS user requirements may not be achieved unless handover to a different system when available is performed. This is critical for uninterrupted real time

applications such as voice or videoconference services.

- Since different service providers may control different wireless networks in an overlapping system over a given area, specific joint radio resource management designs must guarantee network availability and pre-arranged QoS parameters to the end user. In [4], a radio resource management is proposed, on which resources utilization is maximized for the entire overlapping system. Capacity reservation thresholds are defined for prioritizing horizontal and vertical handoff sessions over new originated calls. Bandwidth is initially allocated over specific service areas, then in a real time connection-based approach.

3. ENVIROMENTAL AWARENESS

Because several networks must be continuously monitored for environment awareness, cognitive radio (based on a SDR) appears as one of the best solutions for reaching this goal. Such a software controlled radio not only would enable a terminal to demodulate and compare different types of available networks, but would also -using spectrum sensing capabilities- allow the mobile to identify unused frequencies that belong to different -or the serving network- networks and might become handoff targets [6, 7]. Besides, the capability of reconfiguring the communication link parameters makes SDR very suitable for vertical handoff enabled devices since they need to continuously switch between different networks and technologies, which in most cases use different modulations, coding techniques, data rates and frequencies. High processing power is necessary for running the sensing and handover decision algorithms in real time, as well as for providing seamless service continuity during the handoff procedure.

Some of the network conditions and parameters that should be evaluated for the vertical handoff decision process include:

- SNR
- SINR
- Operating frequencies
- Available bandwidth
- Delay
- Jitter
- BER
- Maximum data rate
- Energy consumption over each network
- Available power in the mobile terminal
- Spectrum usage
- User QoS requirements
- Geographic location
- Security features
- Network operation costs

Parameters selection may be application-specific. In addition, the importance of each parameter during the network selection process could be dynamically adjusted according to current link conditions and data session status. For example, if a large file transfer is closed to be completed, it might not be worth to handover due to the delay imposed by such operation. This delay includes any time necessary to turn on the new wireless network interface -or to adjust the new communication parameters if a SDR capable terminal is used-, the time required to setup the connection with the new network, any time required to exchange session information between the serving and target networks, and the time it takes to connect to the specific server again.

In addition to the network-specific parameters detailed before, some geographic or user-entered information would be substantially helpful for improving between-networks handoff performance [8]. Several hints are detailed below:

- User input: User might instruct the mobile if for example he/she is leaving a building, or when moving too fast.
- Location information: User position within the overlay system may significantly reduce handoff negative impacts on the system, such as ping-pong and small scale fading or shadowing effects.
- Geographic hints: Traces can be used to predict which cells act as gateways to other networks. If a WLAN access point is close to the entrance of the building, a mobile using it might likely require a handoff operation to a higher overlay.
- Handoff frequency: Tracking the frequency of handoffs may be a hint of a mobile possibly leaving the area covered by the current network.

3.1 SDR Architecture

SDR is defined in [9] as a comprehensive, consistent set of functions, components, and design rules according to which radio communications systems may be organized, designed, constructed, deployed, operated and evolved over time. This definition emphasizes the importance of SDR when dealing with a cognitive radio. The radio system needs to be aware of the environment and the different networks in its surroundings, so that it can establish a communication with the network that best suits the needs for the service providers and end users. SDR can offer these requirements by allowing radio dynamic adaptation. Some SDR functional features that permit the radio to adapt are the universality of interfaces (source coding, channel coding, error control and protocols) regardless of multi-technology (FDMA, TDMA, CDMA, and hybrids); internetworking between technologies such as AM, FM, cellular, PCS, and mobile data; complying with standard requirements; and flexibility in its RF component, channel, time slot, power,

bit rate, equalization, channel coding, and error correction.

The main importance that SDR has to offer in the vertical handoff concept is its ability to re-program hardware, which allows sensing and implementing radio communication systems in different modes. When a radio is deciding to handoff a call to another network, it needs to follow the protocol and adjust the logistic in the system level to start communication in an effective way. At the same time, interoperability and global coverage are achieved by being able to use the same radio to talk at different regions of the world.
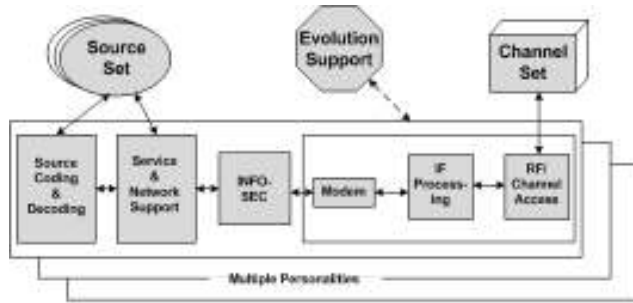

Figure 1. SDR Functional Architecture [8].

The benefits of implementing an SDR in next generations' radios are explained thoroughly by the SDR functional architecture [9]. This architecture is represented in Fig. 1 and it will ease the discussion of the benefits introduced to the vertical handoff capability by each individual component.

The Source set and Source coding & decoding blocks will be used to identify and manage different type of information such as audio, data, or video; and they are important features for determining the network that best fits the user requirements. For example, if the user is having a voice conversation there is no need for high data rate communication, so it will use a different network than if the user is having a live video stream connection. The Service & Network support is the box that controls the data services. In other words, it contains the standards for different technologies. The INFO-SEC is a valuable block for wireless applications since it will protect sensitive data such as financial or private information (personal, authentication, remote access control, etc). For example, if the radio is accessing a web page with secure content –for example, using the HTTPS protocol - the radio will be encouraged to use the INFO-SEC application for more security. In a several networks overlapping scenario, the system may not have to switch to a more secure network if the INFO-SEC capability is enabled, thus, reducing the number of unnecessary handoffs.

The Modem function will be determined according to the Service and Network Support block, and through the

system parameters that best fit the user's needs. The IF processing box will be in charge of the characteristics of the entire IF channels (it will ideally be performed digitally without RF hardware). The RF access, along with the Channel Set, are very important because the antennas should be able to access all available channels, which implies the use of multimode and multi-band antennas for achieving a complete coverage of the spectrum. This way, the perceived QoS could be increased by utilizing the most suitable channel. The Multiple Personality feature allows having different communication systems working simultaneously; increasing functional flexibility, but possibly introducing radio frequency interference. Such functionality would enable joint simultaneously networks usage by the mobile. The Evolution Support is a factor that allows updating the radio in a cost effective way because it is not necessary to replace the whole equipment, but simply to download a piece of software. For example, it may be possible to use the same phone in the US and in Asian countries by simply downloading a program to the phone that contains the network standards. Lastly, the Joint Control is the most important part of the SDR since it integrates user and network interfaces along with multi-user, multi-band, and multimode capabilities. The vertical handoff algorithm will be executed in the Joint Control block.

4. VERTICAL HANDOFF DECISION ALGORITHM

In this section, a vertical handoff algorithm is presented and evaluated based on the test bench illustrated in Fig. 2. Network-specific parameters are included in the graph.
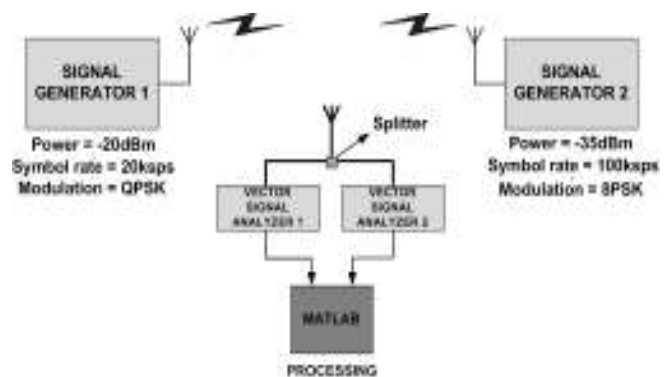

Figure 2. Test bench for creating overlapping networks scenario.

One antenna is connected to the vector signal analyzers using a splitter so that both types of signals are demodulated and downloaded into Matlab, where the vertical handoff algorithm is implemented and evaluated. The overlapping scenario and the trajectory described by the mobile are depicted in Fig. 3.

Following the setup described above, RSS from both networks – after signal was demodulated - was downloaded
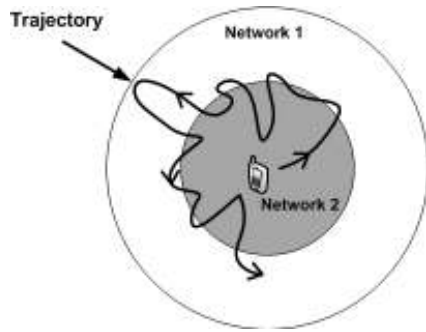
Figure 3. Overlapping networks scenario and mobile trajectory.

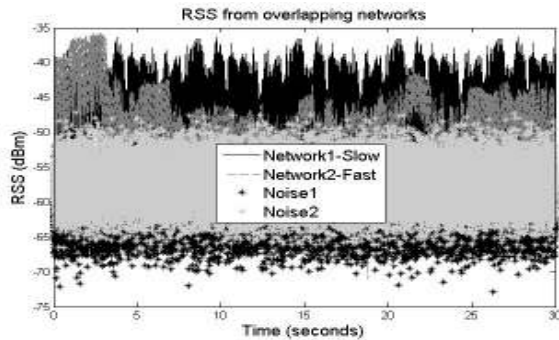into Matlab. In Fig. 4, RSS and noise for both networks are presented.

Figure 4. RSS and noise for the two networks.

The parameters of each network are displayed in Table 1.

Table 1. Overlapping networks' parameters.

	Network 1	**Network 2**
Description	Slow, high coverage area.	Fast, lower coverage area.
Modulation	QPSK	8PSK
Tx power	-20dBm	-35dBm
Symbol rate	20ksps	100ksps
Frequency	915MHz	918MHz
Bandwidth	40KHz	200KHz

Based on the modulation type used by each of the networks (QPSK and 8PSK), we developed an algorithm from which for a given SNR we obtain an estimated BER.

The implemented vertical handoff algorithm weights several conditions to assign a value to each network. Finally, a decision method compares the resulting weighted factors for selecting the best network at any given time. Performance is measured comparing the results given by the vertical handoff algorithm –displaying the network selected during the experiment- with the pre-defined terminal

trajectory. The parameters taken into account are described below.

4.1. Averaging window plus hysteresis

An average is calculated from a certain amount of RSS samples given by the window size [10]. Then, if that average is higher than the other network averaged value by a certain amount of dB (hysteresis), a reward value is given to the network which satisfies the condition. Such a reward value goes from 0 to 1 [0, 0.25, 0.5, 0.75, 1] depending on how many adjacent sample times the hysteresis condition is satisfied (*i, j* denotes each network)..

$$\overline{RSS_i[k]} = \frac{1}{W_{SIZE}} \sum_{n=0}^{W_{SIZE}-1} RSS_i[k-n]$$

$$\overline{RSS_i[k]} > \overline{RSS_j[k]} + hysteresis\_Value$$

4.2 Threshold condition

The threshold condition assigns a reward value if the RSS from the analyzed network is higher than the RSS from the other one, and the other network RSS is below a predefined threshold [11]. The threshold value is a very important parameter that must be specifically designed according to network and propagation conditions. It highly depends on the minimum acceptable value with which communication can still be carried out [1]. Reasonably, it has to be higher than such minimum value so that there is enough time for handoff signaling before communication is completely lost. On the other hand, if it is set too low, communication might be lost because there may not be enough time to perform the handoff procedure (due to handoff delay) if the serving network RSS falls below the minimum acceptable value before the target AP starts serving the call.

4.3 Averaged SNR

Since noise signal was recorded for both networks during the experiment, the SNR is calculated an averaged in the same way as described for the RSS values. This provides a more accurate estimation about which network is experiencing better link conditions.

$$\overline{SNR_i[k]} = \frac{1}{W_{SIZE}} \sum_{n=0}^{W_{SIZE}-1} SNR_i[k-n]$$

4.4 Maximum capacity

Based on Shannon's formula, the maximum achievable capacity for each network is calculated using instantaneous SNR values. Additionally, using the BER estimation stated

before, a more accurate prediction of the maximum achievable data rate is obtained.

$$C = \left[BW_i \cdot Log_2\left(1 + SNR_i\right)\right] \times \left(1 - BER_i\right)$$

According to the maximum throughput that could potentially be reached over each network, a reward value is giving depending on how much higher one is compared to the other. This value range from 0 -when the maximums throughputs are the same- to 1 –when the evaluated network's throughput is more than 5 times higher than the other one.

4.5 Rate of change

A rate of change estimation is performed to find out if a network RSS has been increasing during a certain period of time [12]. This is evaluated by verifying the difference between the current sample with the one before. If this value is higher than zero during several sample times, it may indicate that the user is getting closer to the specific access point. The first step consists in executing an averaging technique for a predefined window size value. Then, contiguous averaged values are subtracted from each other to determine whether or not the rate of change is increasing; in which case, a specific reward value would be gained by the given network.

$$rate_i[k] = \overline{RSS_i[k]} - \overline{RSS_i[k-1]}$$

A different window size than the one used for the averaging procedure was utilized as parameter in order to provide more flexibility to the tuning of the handoff decision algorithm.

4.6 Equivalent SNR

Due to the fact that each network uses a different modulation technique and transmits at different power levels, a reward parameter is given to the network that is capable of providing the same or a higher data rate than the other one, based on Shannon's formula and instantaneous measured SNR values. This is performed in a similar way as proposed in [13]. This technique is useful for more accurately estimating which network has the higher equivalent RSS value, rather than comparing absolute RSS values solely.

$$C_i = BW_i \cdot Log_2\left(1 + SNR_i\right)$$

Equating the 2 capacity equations (one for each network) allows for an equivalent SNR estimation (the minimum SNR that would enable to provide the same data rate currently achievable using the other network).

$$eq\_SNR_i = \left[\left(1 + SNR_j\right)^{\frac{BW_j}{BW_i}}\right] - 1$$

It is important to mention an important parameter that was added to the algorithm, a dwell time. It is different for each reward function, and determines for how long a condition must be satisfied before any reward value is obtained.

Finally, the total reward function for each network is calculated as follows, assigning a weighted value to each handover condition [14, 15]:

$$Network_i = \sum_{k=1}^{n} w_k \cdot condition_{k,i}$$

Where w_k is the weight given to every condition, and $condition_{k,i}$ represents the reward given to network i for satisfying the condition k.

After tuning the parameters the total reward function was calculated as shown below.

$$Network_1 = \begin{cases} 0.2 \cdot avg\_hyst_i + 0.2 \cdot threshold_i \\ + 0.1 \cdot rate_i + 0.25 \cdot \max\_capacity_i \\ + 0.15 \cdot avg\_SNR_i + 0.1 \cdot eq\_SNR_i \end{cases}$$

A specific target network is selected if the following condition is satisfied. If neither network satisfies it, the serving network continues serving the session.

$$Network_i \geq Network_j + 0.05$$

Fig. 5 presents the results after executing the algorithm over the experiment. It displays the data rate during the simulation depending on which of the networks is serving the data session at any given time. The straight square wave represents the data rate over the experiment using the theoretical symbol rates for each network (the horizontal line represents the average value).
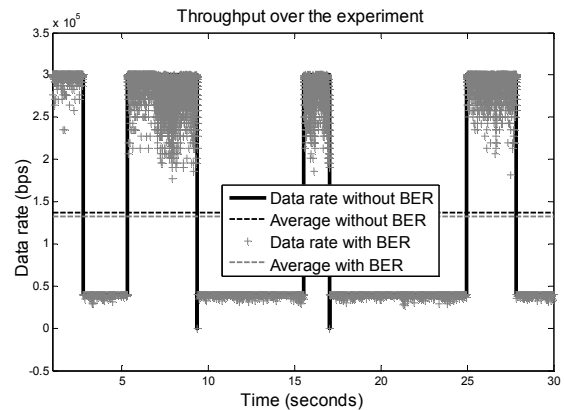

Figure 5. Vertical handoff algorithm results.

Further, the same graphs can be visualized when BER is considered as a limiting factor. The number of times that the data rate took the 0kbps value indicates the number of times (2) the RSS from the serving access point fell below the minimum required value, causing a forced terminated call. Given the fact that the user motion during the experiment was known, the results are accurate since the algorithm selected in general the suitable network with a low number of handoffs and forced terminated calls (see Fig. 3), by choosing the fast network when available and proper link conditions were existing.

5. CONCLUSIONS AND FUTURE WORK

Interoperability is one of the key aspects of today's wireless systems. Vertical handoff offers the possibility of integrating different networks for maximizing network efficiency and user satisfaction. It allows users to select the more appropriate connection at a given time, and get larger coverage areas. As private and public wireless networks continue being deployed, heterogeneous systems are generated. In order to satisfy user QoS needs and service continuity, mechanisms for handing over between different wireless access technologies must be designed. This includes not only technical aspects, but also agreements between service providers. A vertical handoff algorithm was presented, evaluated and compared with the expected results of a pre-defined experiment. Different parameters, which are useful for identifying differences in heterogeneous environments, were included in the analysis.

External positioning systems could provide enough information to determine users' location, as well as accurate mobility predictions, which would be useful for improving the network selection process.

Future work includes adding more parameters to the handoff algorithm by incorporating awareness to SINR, security, power available in the mobiles, and coding. Additionally, being able to dynamically adapt the algorithm's parameters would offer a more responsive system. On the other hand, implementations with several access points for each network will provide a more realistic scenario.

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