The text content of the image is as follows:

**D 6.12.5 Limited proof-of-concept of WINNER co-operation architecture**

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**Abstract:**

This is an internal working document that describes the initiative of WP4 of the project WINNER to develop, validate and demonstrate a platform that can be used to prove the concept of Cooperative RRM in Systems Beyond 3G.

**Keyword list:** RRM platform, CoopRRM, trials, WINNER, WLAN, Validation

**Disclaimer:**
Executive Summary

This is a public document that describes the initiative of WP4 of project WINNER II to develop a platform that can be used to validate and demonstrate the WP4 concepts of wireless networks cooperation in Systems Beyond 3G. This initiative brings an added value to the overall objectives of WINNER by providing an emulation and demonstration platform for the proof-of-concept of the inter-RANs cooperative schemes and WINNER internal inter-modes functionalities.

This platform is based on the concept defined by projects CAUTION and CAUTION++, and will validate the WINNER System Concept on aspects of Radio Resource Management. This activity started at the last semester of Phase I and is now continued in Phase II.

The platform is based on real-time monitoring of the WINNER RAN and legacy RANs, and will support of service requests and user-/system-initiated intermode and intersystem handover, as well as congestion management and QoS guarantee.

This ambitious activity obviously requires the existence of a WINNER RAN, which does not exist at the moment. The WINNER RAN, however, can be successfully approximated by setting-up a testbed that partially consists of emulators. The platform is scalable and modular, so that any additional WINNER feature and new relevant specifications can be added at any given time. Interaction with other WPs will ensure that at the end the project will have a powerful testbed.

In the context of the WINNER project, simultaneously with the RRM trial, there is another trial running, which is related to the WINNER air interface, the channel models and in general the Physical Layer of WINNER. In order to be able to demonstrate in various conferences a good general image of the WINNER project, the RRM trial and the PHY trial were integrated in one WINNER trial. This document, describes the integrated WINNER trial and its results in the demonstrations in various conferences. In the last chapter, the work that was performed in the WWI Cross Issue Validation group is presented, where the RRM trial is one part of a global WWI demonstrator that talks about a possible day in the future wireless life.
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</table>
## List of Acronyms and Abbreviations

<table>
<thead>
<tr>
<th>BS</th>
<th>Base Station (new term for former WINNER Access Point)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GUI</td>
<td>Graphical User Interface</td>
</tr>
<tr>
<td>KPI</td>
<td>Key Performance Indicator</td>
</tr>
<tr>
<td>NMS</td>
<td>Network Management System</td>
</tr>
<tr>
<td>RCM</td>
<td>Run Control Module</td>
</tr>
<tr>
<td>RTTM</td>
<td>Real Time Traffic Measurements</td>
</tr>
<tr>
<td>TLS</td>
<td>Traffic Load Scenario</td>
</tr>
<tr>
<td>UT</td>
<td>User Terminal</td>
</tr>
</tbody>
</table>
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1. Introduction

Next-generation wireless networks will be a conglomeration of different networking and radio access technologies. This will allow global roaming across systems based on individual access technologies. In such a challenging scenario the specific Radio Resource Management functionalities (RRM) of each radio access network (RAN) should be coordinated not only to provide the most efficient use of available resources per access technology but also to make possible the coexistence of essentially different radio concepts.

The IST project WINNER develops a new air-interface and RAN that needs to coexist with a number of legacy systems, namely, GPRS, UMTS, and WLAN 802.11. Such a heterogeneous scenario requires a cooperation scheme that ensures seamless and efficient inter-working among the RANs to satisfy the user demands on an individual basis. For this purpose a number of RRM cooperation mechanisms and algorithms related to mobility management including handover, admission control, congestion control and quality of service were proposed earlier in phase I deliverables D4.1, D4.2, and D4.3. The work presented here is a next step in this research and has the objective to implement the proposed mechanisms into an RRM platform. Such a platform will become an emulation tool that can show how the various RRM mechanisms can be triggered and how the proposed cooperation architecture can support them.

The cooperation mechanisms are schemes for mobility management, including vertical handover, admission control, congestion and load control, and QoS management. The cooperation mechanisms are proposed and developed at the radio segment level of B3G RANs, and not only at higher layers. They are envisioned as built-in features of the new B3G system and may be implemented at network elements of the rank of Node B (or equivalent) or below. The cooperation mechanisms are supported by a specially designed architecture as shown in Figure 1.

![Figure 1: Cooperation architecture for support of the proposed cooperation mechanisms](image)

The different RATs have their individual specific RRM logical entity (SRRM) that works in a distributed manner, and that are coordinated by the CoopRRM entity, which is envisaged to be located in the new WINNER network. The inter-RANs cooperation algorithms (cooperation mechanisms) will run in the CoopRRM and SRRM entities. The CoopRRM interfaces with other CoopRRM of the same or different operators.

The logical functionality of the CoopRRM is divided in a common part (RRM-g) and a specific part (RRM-s) for each RAN with the common part containing the functionalities common to all RANs. It
provides a common interface towards upper layer functions/protocols. The specific part handles the specific details of each RAN.

The CoopRRM location is flexible and it could be located inside or out of WINNER RAN, in a neutral point between the WINNER RAN and the legacy RANs. The SRRM entities have a monitoring functionality, when a measurement surpasses a threshold a trigger will initiate a request of actuation to the CoopRRM entity.

The innovative part of the proposed here implementation of the WINNER cooperation mechanisms is that the system integration is realized to allow coexistence of legacy networks (e.g., WLAN, UMTS and GPRS) with the WINNER RAN, which handles the radio upon divided bandwidth and assigned frequencies according to the service provided from the operator. The latter is emulated as part of an AP, which provides different bandwidth requirements under the same frequency or the same bandwidth under different frequencies bands as an AP of 802.11a/b/g emulation of the WINNER RAN.

This document is further organized as follows. In chapter 2 there are described the components and the networking of the WINNER RRM platform in their current state. In chapter 3 there are described the key WINNER RRM mechanisms that are developed in each one of the components of the platform and in chapter 4 there is a try for a preliminary validation of the developed mechanisms. Finally in chapter 5 there is the conclusion of the document.
2. RRM Cooperation architecture

Figure 2.1 shows the high level architecture of the demonstrator platform. In the upper part of the figure, the components of the WINNER network are shown: the Access Point, will use 802.11a/b/g wireless protocols, emulating a WINNER Base Station with three WINNER System Modes (in the figure we show three antennas for the three modes of WINNER, but it will only be one AP), the Access Control Server (ACS) will control the state of the WINNER network and the SRRM unit, they monitor the state of the network and forward alarms to the CoopRRM entity. In the lower part of the figure, the components of the legacy RAN are shown. At the legacy RAN we have the Monitoring Unit (part of the SRRM_L), that monitors the state of the RAN. Finally, the User Terminal is capable of connecting to all the modes of the WINNER network and the legacy RAN, using a high level application that will exchange XML formatted messages with the CoopRRM.

![Image of Demonstration platform Architecture]

In Figure 2.2 it is depicted the WINNER Coop RRM platform along with the interfaces that are used for the connections between the components of the platform.

The following interfaces are defined:

- **C_w interface**
  This is the interface between the SRRM_w and the ACS. Over this interface, RTTMs are transferred from ACS to the SRRM_w for monitoring purposes. In addition, when the local RRM techniques are applied by the SRRM_w, the commands are forwarded to the ACS over this interface. It is also used to transfer the user service requests for intra-WINNER management.

- **C_PW interface**
  This is the interface between the CoopRRM and the SRRM_w. This interface is used to send alarms to the CoopRRM, to provide the network status to the CoopRRM, on demand, and allows the messages for the RRM-s techniques (including handover command) from the CoopRRM. It is also used to forward new service requests (that cannot be handled inside WINNER) to the CoopRRM entity.

- **C_PL interface**
  This is the interface between CoopRRM and SRRM_L. This interface is meant for the exchange of alarm messages from SRRM_L and also for the status demand messages from SRRM_L.
It should be highlighted that the above figures depict the initial architecture of the CoopRRM platform. This is based on the on-going process of specifying WINNER concepts and components, but changes are expected in such an ambitious R&D project. In any case of modification of the initial assumptions, the CoopRRM platform will be developed according to the proposed architecture, however bringing components and interfaces in-line with the guidelines from the project. For instance, there is a new proposal on merging ACS with SRRMw, which will make the topology more compact and flexible. In this case prototype components will be merged, keeping though the functionalities described bellow.
3. RRM Cooperation mechanisms

3.1 Priority table

In both algorithm further discussed we use user and application priorities. We have defined a two-level priority which is depending both on the user profile and on the application profile. For the user prioritisation, we will have 4 degrees of priority, 3 being directly associated with the contract of the user (i.e. what kind of offer he chose) and one, called “emergency”, that is designed for professionals which could need fast access to the network at any time (e.g. policemen, paramedics, firemen,...). The application priority is not yet defined, but it will allow a more subtle sorting of the user. Priorities are sorted in an ordered table containing every user and associated application(s).

3.2 Admission control

Admission Control takes place as soon as a user requests the use of a new application. The Admission Control process begins with a check of the information of the user profile, in order to know if the user can claim access to the operator network, otherwise he is directly rejected, and to the WINNER network. If he doesn’t have access to WINNER, he is redirected. The profile of the application is then checked to determine which operation mode will be chosen. On the flowchart, the process is depicted only for mode 2 but it will be the same for each mode. At this step, the algorithm needs to verify if there are queued sessions, waiting to enter the mode. In the case there are, the user is redirected. Users with a high degree of priority such as “emergency” users or users coming from a handover will not have to take this step, they will automatically be served first. Then, if the mode chosen is available, the user is granted with access. Otherwise, the algorithm will look at the priority table to see if we can use the resources of one or several lower priority sessions (namely by moving these sessions to other RANs or by decreasing their QoS). If admission cannot be achieved, the user is redirected.

The redirection consists of looking on the other RANs that are compatible with the application requested. On each compatible network, the algorithm checks if it is available or if resources can be withdrawn from lower priority sessions (like described in the WINNER part). As soon as a network becomes available, handover is performed, and our user is directed on one of the legacy RANs. If none RANs becomes available, the user is eventually rejected.

After admission is obtained, it is necessary to perform an update of the priority table including the new user.

The admission control algorithm is presented below:
User requests new application

Is user from operator? NO

WINNER user? YES

Mode of operation? 1

Emergency or HO user? NO

Are there already queued sessions in this mode? YES

Is the mode available? NO

Is the requested application compatible with other RANs? YES

First unchecked compatible network available? NO

Perform ISHO for our user

Can we obtain sufficient resources for our user by performing ISHO on ongoing lower priority sessions? YES

Can we obtain sufficient resources for our user by degrading QoS of ongoing lower priority sessions? NO

Perform ISHO for these sessions

Can we obtain sufficient resources for our user by degrading QoS of ongoing lower priority sessions? YES

Degrade QoS of these sessions

All compatible networks checked? NO

NO

User rejected

YES

User accepted
3.3 Congestion control

Congestion control is a task that is always in execution. The congestion control process is divided in three phases.

The first phase is the most common one, the normal network operation of the network. During this phase, the network will periodically look at the KPIs in order to be aware of a congestion situation. If congestion is detected, we enter the congestion resolution phase. The first action is to reject every new session request. Then the algorithm checks if there are users consuming more resources that they were initially granted with, and decrease their bitrate at the normal level. If this is enough to get out the congestion situation, we return in the normal operation phase without taking the congestion recovery step. If it is not sufficient, the algorithm tries as much as possible to send the users on other RANs, beginning with the high-prioritised ones. If this is still not sufficient, it divides by two the bitrate of each session, beginning with low-prioritised ones. Eventually, it drops sessions, beginning with low-prioritised ones, until the networks gets out the congestion situation. We can also think at other RRM techniques to include in this part of the algorithm, for example, in case we have a user running multiple applications, starting with decreasing the bitrate of his lowest priority application.

Once we are out the congestion resolution phase, and if the bitrate dividing process has been used, we go through the congestion recovery phase. In this part of the algorithm, we try, beginning with high prioritised users, to restore bitrates previously degraded, without getting again in congestion phase of course. At the end of this process, the system can operates normally again.

The congestion control algorithm is presented below:
Normal operation of the system

Congestion?

YES

NO

Reject any new session request

Any session violating the agreement?

YES

NO

Decrease bitrate of these sessions

YES

NO

ISHO possible for highest priority unchecked session?

YES

NO

All sessions checked?

YES

NO

Decrease lowest priority undecreased session's bitrate by half

YES

NO

Drop lowest priority session

YES

NO

Can we restore datarate of the highest priority decreased unchecked session without having congestion?

YES

NO

Restore datarate

CONGESTION RECOVERY PHASE

YES

NO

All sessions checked?

YES

NO

PERFORM ISHO
4. Simulation results

In this section the RRM simulations that have been carried out during the WINNER project are presented. In section 4.1 traffic modelling characteristics are discussed, while in 4.2 the simulation environment is described. In section 4.3 initial simulations are presented, focusing on the load and the delay. Finally, in section 4.3 future work dealing with cognitive RRM is introduced.

4.1 Traffic modelling

4.1.1 Applications

In the simulation part the applications are defined following what was described in the previous parts. Nevertheless, some assumptions have been done to facilitate their handling.

First of all, the classification coming from recommendations found in [Umt] has been performed. In this publication, a prevision of what will be the applications available in the year 2012 and what will be their penetration factor is proposed. This was very useful since it covers exactly the moment in time at which our B3G system will be in operation. Moreover, the applications included in this survey are globally the same that we introduced previously. Table 4.1 presents the different service categories and their associated penetration factors as expected in 2012 together with the service classes associated and their penetration factors. The penetration factors for the service classes have been determined by dividing each service category penetration factor by the number of service classes it encloses.

<table>
<thead>
<tr>
<th>Service Category</th>
<th>Service Category Penetration Factor</th>
<th>Service Class</th>
<th>Service Class Penetration Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobile Intranet / Extranet Access</td>
<td>31%</td>
<td>12. LAN Access and File Services</td>
<td>31%</td>
</tr>
<tr>
<td>Customised Infotainment Services</td>
<td>17%</td>
<td>8. Simple Telephony and Messaging</td>
<td>17%</td>
</tr>
<tr>
<td>Multimedia Messaging Services</td>
<td>4%</td>
<td>13. Multimedia Messaging</td>
<td>4%</td>
</tr>
<tr>
<td>Mobile Internet Access</td>
<td>7%</td>
<td>10. Geographic Datacast</td>
<td>1.17%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>14. Lightweight Browsing</td>
<td>1.17%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15. File Exchange</td>
<td>1.17%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>16. Video Streaming</td>
<td>1.17%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>17. High Quality Video Streaming</td>
<td>1.17%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>18. Large File Exchange</td>
<td>1.17%</td>
</tr>
<tr>
<td>Location - Based Services</td>
<td>1%</td>
<td>3. Short Control Messages and Signalling</td>
<td>0.33%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4. Simple Interactive Applications</td>
<td>0.33%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6. Geographic Interactive Multimedia Broadcast</td>
<td>0.33%</td>
</tr>
<tr>
<td>Simple and Rich Voice Services</td>
<td>40%</td>
<td>1. Real Time Collaboration and Gaming</td>
<td>6.67%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Geographic Real Time Datacast</td>
<td>6.67%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5. Interactive High Multimedia</td>
<td>6.67%</td>
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<tr>
<td></td>
<td></td>
<td>7. Interactive Ultra High Multimedia</td>
<td>6.67%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9. Data and Media Telephony</td>
<td>6.67%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11. Rich Data and Media Telephony</td>
<td>6.67%</td>
</tr>
</tbody>
</table>

The other important application’s parameters for the simulation are the duration and the data rate. Regarding the duration, we have applied what was described in III.2.2, that is to say that every application running lasts for its expected download time. Concerning the data rate, we have chosen to use for the simulated data rate the average of the minimum and maximum required data rates expressed in Table II.4. The simulated data rate values are presented in Table 4.2.


### Table 4.2: Simulated data rate values

<table>
<thead>
<tr>
<th>Service Class</th>
<th>Minimum required data rate (kb/s)</th>
<th>Maximum required data rate (kb/s)</th>
<th>Simulated data rate (kb/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Real Time Collaboration and gaming</td>
<td>1x10^24</td>
<td>20x10^24</td>
<td>10x10^24</td>
</tr>
<tr>
<td>2. Geographic real time datacast</td>
<td>2x10^24</td>
<td>5x10^24</td>
<td>3.75x10^24</td>
</tr>
<tr>
<td>3. Short Control messages and signalling</td>
<td>8</td>
<td>64</td>
<td>28</td>
</tr>
<tr>
<td>4. Simple interactive applications</td>
<td>64</td>
<td>512</td>
<td>224</td>
</tr>
<tr>
<td>5. Interactive high multimedia</td>
<td>2x10^24</td>
<td>5x10^24</td>
<td>3.75x10^24</td>
</tr>
<tr>
<td>6. Geographic interactive multimedia broadcast</td>
<td>2x10^24</td>
<td>5x10^24</td>
<td>3.75x10^24</td>
</tr>
<tr>
<td>7. Interactive ultra high multimedia</td>
<td>1x10^24</td>
<td>50x10^24</td>
<td>25x10^24</td>
</tr>
<tr>
<td>8. Simple telephony and messaging</td>
<td>8</td>
<td>64</td>
<td>28</td>
</tr>
<tr>
<td>9. Data and media telephony</td>
<td>64</td>
<td>512</td>
<td>224</td>
</tr>
<tr>
<td>10. Geographic datacast</td>
<td>64</td>
<td>512</td>
<td>224</td>
</tr>
<tr>
<td>11. Rich data and media telephony</td>
<td>2x10^24</td>
<td>5x10^24</td>
<td>3.75x10^24</td>
</tr>
<tr>
<td>12. LAN access and file services</td>
<td>512</td>
<td>50x10^24</td>
<td>24.75x10^24</td>
</tr>
<tr>
<td>13. Multimedia messaging</td>
<td>8</td>
<td>64</td>
<td>28</td>
</tr>
<tr>
<td>14. Lightweight browsing</td>
<td>64</td>
<td>512</td>
<td>224</td>
</tr>
<tr>
<td>15. File exchange</td>
<td>2x10^24</td>
<td>5x10^24</td>
<td>5x10^24</td>
</tr>
<tr>
<td>16. Video streaming</td>
<td>2x10^24</td>
<td>5x10^24</td>
<td>5x10^24</td>
</tr>
<tr>
<td>17. High quality video streaming</td>
<td>2x10^24</td>
<td>30x10^24</td>
<td>14x10^24</td>
</tr>
<tr>
<td>18. Large files exchange</td>
<td>1x10^24</td>
<td>50x10^24</td>
<td>25x10^24</td>
</tr>
</tbody>
</table>

#### 4.1.2 Users

For the simulation the modelling of the users has been done through the use of the user profile. The choice has been made to allow the user to run only one application at a time, which is not a critical assumption since, from a simulation point of view, two users with same priority running respectively application x and y are the same than one user running both applications x and y.

At the simulation level the important parameters for a user are the location, the priority level and the application. For simulation handling matters we have defined some groups of users, which contain users having all same location, same priority and same application. We have decided to let the program choose the location of the groups of users. The users are then randomly placed within the area of study following a uniform distribution. On the other hand, the priority level of the group is to be manually assigned. The user is then associated with an application, that is to say with a certain running time, the application’s expected download time, and a certain data rate, the application’s simulated data rate, as previously described. The application repartition within the users is of course meant to fit the penetration factors previously introduced.

#### 4.2 Simulation environment modelling

Different choices have been made to define the environment of simulation. First of all, despite hexagonal cells are more common, we have decided to use square-shaped cells as done in [Win44]. The square shape is not a critical parameter for our model and it is the easiest shape to define in computing language.

Four parameters are used to define each cell: the RAN and mode type, the cell coverage, the cell capacity and the cell location. With this information every cell can be uniquely identified. Besides, we decided to use typical cells for each RAN or mode that is to say that within the same RAN or mode, all the cells will have the same coverage area and capacity value.

Our first assumption is that we use a total of 22 cells in our simulations. These 22 cells are composed of 9 WINNER #1 cells, 6 WINNER #2 cells, 1 WINNER #3 cell, 1 GPRS cell, 1 UMTS cell and 1 WLAN cell.
4.2.1 Cells disposition

Concerning the coverage, we have chosen to use a scalable pattern and hence the values are expressed in an arbitrary unit. The choices made in terms of coverage are summed up in Table 4.3.

<table>
<thead>
<tr>
<th>RAN / Mode</th>
<th>GPRS</th>
<th>UMTS</th>
<th>WLAN</th>
<th>WINNER #1</th>
<th>WINNER #2</th>
<th>WINNER #3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Square edge length (a.u.)</td>
<td>8</td>
<td>10</td>
<td>6</td>
<td>6</td>
<td>10</td>
<td>30</td>
</tr>
<tr>
<td>Coverage (a.u.²)</td>
<td>64</td>
<td>100</td>
<td>36</td>
<td>36</td>
<td>100</td>
<td>900</td>
</tr>
</tbody>
</table>

We have limited the area of study to the highest coverage area presented in Table 4.1. This means that the whole area of study will be entirely covered by the one WINNER #3 cell. The positioning of the cells is done by placing the upper left vertex of the square-shaped cell in the area of study. The coordinates of the upper left vertex for each cell are presented in Table 4.4.

<table>
<thead>
<tr>
<th>Cell ID</th>
<th>RAN / Mode</th>
<th>Upper left vertex coordinates</th>
</tr>
</thead>
<tbody>
<tr>
<td>cellw1_1</td>
<td>WINNER #1</td>
<td>(02;28)</td>
</tr>
<tr>
<td>cellw1_2</td>
<td>WINNER #1</td>
<td>(12;28)</td>
</tr>
<tr>
<td>cellw1_3</td>
<td>WINNER #1</td>
<td>(22;28)</td>
</tr>
<tr>
<td>cellw1_4</td>
<td>WINNER #1</td>
<td>(02;18)</td>
</tr>
<tr>
<td>cellw1_5</td>
<td>WINNER #1</td>
<td>(12;18)</td>
</tr>
<tr>
<td>cellw1_6</td>
<td>WINNER #1</td>
<td>(22;18)</td>
</tr>
<tr>
<td>cellw1_7</td>
<td>WINNER #1</td>
<td>(02;08)</td>
</tr>
<tr>
<td>cellw1_8</td>
<td>WINNER #1</td>
<td>(12;08)</td>
</tr>
<tr>
<td>cellw1_9</td>
<td>WINNER #1</td>
<td>(22;08)</td>
</tr>
<tr>
<td>cellw2_1</td>
<td>WINNER #2</td>
<td>(00;30)</td>
</tr>
<tr>
<td>cellw2_2</td>
<td>WINNER #2</td>
<td>(10;30)</td>
</tr>
<tr>
<td>cellw2_3</td>
<td>WINNER #2</td>
<td>(20;30)</td>
</tr>
<tr>
<td>cellw2_4</td>
<td>WINNER #2</td>
<td>(00;10)</td>
</tr>
<tr>
<td>cellw2_5</td>
<td>WINNER #2</td>
<td>(10;10)</td>
</tr>
<tr>
<td>cellw2_6</td>
<td>WINNER #2</td>
<td>(20;10)</td>
</tr>
<tr>
<td>cellw3</td>
<td>WINNER #3</td>
<td>(00;30)</td>
</tr>
<tr>
<td>cellumts</td>
<td>UMTS</td>
<td>(01;19)</td>
</tr>
<tr>
<td>cellgprs</td>
<td>GPRS</td>
<td>(14;21)</td>
</tr>
<tr>
<td>cellwlan</td>
<td>WLAN</td>
<td>(24;18)</td>
</tr>
</tbody>
</table>

The overall cell disposition along the whole area of study is depicted in Figure 4.1. It shows how we emulate the environment to perform the simulations.
4.2.2 Cells capacity

Regarding the capacity, we have decided to use the same value for all the legacy RANs’ cells while the value for all the WINNER cells is twice greater.

Then, to determine the total capacity of the network, we start with the assumption that we need to host 10,000 users at most, i.e. for a total load of 100%. Using the applications’ penetration factors and simulated data rate described in 4.1.1, we can determine the total capacity value, using equation 4.1.

\[ \text{TotalCapacity} = N_{u_{\text{max}}} \times \prod_{i=1}^{N_{SC}} f_i \times DR_i \]  

(4.1)

Where
- \( N_{u_{\text{max}}} \) is the maximum number of users (10,000 in our case)
- \( N_{SC} \) is the total number of service classes (18 in our case);
- \( f_i \) is the penetration factor of the \( i^{th} \) service class;
- \( DR_i \) is the simulated data rate of the \( i^{th} \) service class.

By applying this formula we get the value of 113,680 Mb/s for the total capacity of the entire network.

Capacity values for each cell depending on the RAN or mode it belongs to are summed up in Table 4.5.
### 4.3 Results

#### 4.3.1 Load calculation

The load is calculated independently for each cell. It is expressed as the occupation of the total capacity of the cell, and the load value is then comprised between 0 and 100.

As stated previously, the calculation of load for WINNER has been performed taking only into account the bandwidth metric, in the data rate sense. For simplicity matters the same process has been applied to other RANs. This allows the algorithm to work with a generic formula. Moreover it provides load values that are coherent for the simulation, i.e. the load values for each RAN are comparable since they do not come from totally different calculations.

In order to apply this method, the data rate utilised by each user, depending on the application required, is determined. By adding the data rates of all the users, the load value is obtained, as depicted by equation 4.2.

\[
\text{Load}_n = \frac{\sum_{i}^{} N_{nu} \times DR_i}{C_n} \quad (4.2)
\]

Where:
- \( \text{Load}_n \) is the load of the \( n \)th cell;
- \( C_n \) is the total capacity of the \( n \)th cell;
- \( N_{nu} \) is the total number of users running applications in the \( n \)th cell;
- \( DR_i \) is the data rate of the \( i \)th user.

#### 4.3.2 Delay

##### 4.3.2.1 Typical delay

For the simulation a typical delay has been defined for each RAN and for each WINNER mode. The typical delay is the average packet delay happening when the network is in the normal operation phase. Typical delay values are summed up in Table 4.6:

<table>
<thead>
<tr>
<th>RAN</th>
<th>Typical delay value (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPRS</td>
<td>200</td>
</tr>
<tr>
<td>UMTS</td>
<td>100</td>
</tr>
<tr>
<td>WLAN</td>
<td>20</td>
</tr>
<tr>
<td>WINNER #1</td>
<td>20</td>
</tr>
<tr>
<td>WINNER #2</td>
<td>100</td>
</tr>
<tr>
<td>WINNER #3</td>
<td>200</td>
</tr>
</tbody>
</table>

This parameter is determined regarding what are the delay requirements of applications that can operate on it and withdrawing an average tendency. It bears no QoS properties but only the big picture about how delay can be included in the algorithms.
4.3.2.2 Delay modelling

A mathematical description of delay has been embedded in our simulation environment. It has been found in [Xia03] that in a packet-switched network, the packet delay varies exponentially versus the load of the network. Hence a formula has been derived to obtain a relation between load and delay that takes into account the exponential dependency. In low network load situation, the delay value is the typical delay value previously introduced. When the load increases and gets in the congestion zone, the delay value then augments very quickly. Moreover the formula considers the influence of the congestion threshold parameter, that is to say that the congestion zone will be reached sooner or later depending on the threshold chosen for the congestion control algorithm. The general formula is explicited in equation 4.3. It comes from empirical tests and ensures the assumptions that no significant change in delay may occur before the 40% load value is reached and that the higher delay value (i.e. for the 100% load value) must remain coherent with our environment that is to say between typical delay + 500 ms and typical delay + 1000 ms.

\[
\text{Delay} = \text{TypDel} + 120.0 \times \frac{\text{Load} \times \text{Step}}{12}
\]

(4.3)

Where
- \(\text{TypDel}\) is the typical delay value in ms;
- \(\text{Load}\) is the load value in percentage of the total capacity;
- \(\text{Step}\) is the parameter, depending on the congestion threshold chosen, ensuring that no significant change occurs in delay before the 40% load value. It is expressed in percentage of the total capacity. It is expanded in equation 4.4.

\[
\text{Step} = 40 + \frac{\text{CongThresh}}{2}
\]

(4.4)

Where
- \(\text{CongThresh}\) is the load value, expressed in percentage of the total capacity, chosen in the congestion control algorithm to identify a congestion situation.

Figure 4.2 shows the delay variations in a network with 20 ms as typical delay value. It represents the packet delay in ms versus the load of the network in percentage of the total capacity, for different values of the congestion threshold.
4.4 Cognitive WINNER RRM Simulation

4.4.1 Simulation Scenario
In order to carry out the simulation of cognitive radio resource management, the following scenario is considered:
1. The simulation is done in heterogeneous wireless scenario, including WINNER, UMTS, and WLAN
2. Radio resource management is carried out in order to avoid and solve the network congestion.
3. Some techniques are applied such as admission control, Inter Mode Handoff (IMHO) and Inter System Handoff (ISHO)
4. An artificial intelligence, such as Fuzzy Logic, is applied to trigger the HO, i.e. whether or not the Handoff process is going to be taken, and also in making the decision of admission control and HO processes, i.e. choosing the most appropriate cell for certain session after the admission control or HO process.

4.4.2 Assumptions and limitations
Several assumptions and limitations are made in order to simplify the simulation and to be more focus on the main objective which is on cognitivity of radio resource management in heterogeneous wireless network.
1. Only the session, i.e. flow context, is considered without caring about the user context, such as its priority, type of contract, etc.
2. Mobility is not considered
3. Five cells are considered, i.e. Winner LA, Winner MA, Winner WA, UMTS, and WLAN
4. The cells are considered to be overlapping with each other
5. Four traffic classes are considered:
   a. VoIP (real time and low B/W)
   b. Web browsing (non-real time and low B/W)
   c. Video streaming (real time and high B/W)
   d. File transfers (non-real time and high B/W)
6. Each traffic class has different priority where traffic class (a) is the highest while (d) is the lowest priority. Furthermore, each of them has different characteristics in terms of minimum delay and required rate, packet size, session arrival rate, and duration. They are described in the following table:

<table>
<thead>
<tr>
<th></th>
<th>Video streaming</th>
<th>VoIP</th>
<th>File transfer</th>
<th>Web browsing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum delay</td>
<td>0.08</td>
<td>0.15</td>
<td>0.5</td>
<td>1</td>
</tr>
<tr>
<td>(s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Required rate (kbps)</td>
<td>500</td>
<td>32</td>
<td>512</td>
<td>64</td>
</tr>
<tr>
<td>----------------------</td>
<td>-----</td>
<td>----</td>
<td>-----</td>
<td>----</td>
</tr>
<tr>
<td>Packet size (bytes)</td>
<td>1500</td>
<td>70</td>
<td>512</td>
<td>512</td>
</tr>
<tr>
<td>Duration (s)</td>
<td>Exponentially distributed µ: 150 s, min: 10 s, max: 600 s</td>
<td>Exponentially distributed µ: 120 s</td>
<td>File size: uniformly distributed, min: 10 kB, max: 70 MB, overhead: 24 bytes</td>
<td>1 s</td>
</tr>
</tbody>
</table>

7. Session arrival rate is defined for each cell. For WINNER RAN, three traffic load scenarios (TLS) are defined, i.e. low, medium, and heavy, while for UMTS and WLAN the TLS are assumed to be all low arrival rate. Furthermore, they are all assumed to follow the Poisson distribution. This is mentioned in the following table [Kim06]:

<table>
<thead>
<tr>
<th>Session arrival rate (sessions/second)</th>
<th>Video streaming</th>
<th>VoIP</th>
<th>File transfer</th>
<th>Web browsing</th>
</tr>
</thead>
<tbody>
<tr>
<td>WINNER Low</td>
<td>0.041</td>
<td>0.1</td>
<td>0.041</td>
<td>9.23</td>
</tr>
<tr>
<td>WINNER Medium</td>
<td>0.059</td>
<td>0.3</td>
<td>0.059</td>
<td>13.185</td>
</tr>
<tr>
<td>WINNER Heavy</td>
<td>0.076</td>
<td>0.6</td>
<td>0.076</td>
<td>17.141</td>
</tr>
<tr>
<td>UMTS</td>
<td>0.02</td>
<td>0.2</td>
<td>0.02</td>
<td>8</td>
</tr>
<tr>
<td>WLAN</td>
<td>0.04</td>
<td>0.2</td>
<td>0.03</td>
<td>9</td>
</tr>
</tbody>
</table>

8. Capacity of each cell is defined as follows:

<table>
<thead>
<tr>
<th>Capacity</th>
<th>WINNER LA</th>
<th>WINNER MA</th>
<th>WINNER WA</th>
<th>UMTS</th>
<th>WLAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>325 Mbps</td>
<td>150 Mbps</td>
<td>65 Mbps</td>
<td>10 Mbps</td>
<td>54 Mbps</td>
<td></td>
</tr>
</tbody>
</table>

9. The input parameters of HO initiation are delay (D) and offered traffic (T). These are calculated for each cell and for each traffic class, based on the formula in **WINNER D 6.2**. How they are calculated is explained as follows:

Offered traffic per traffic class: \( T_n = \sum P \cdot \mu \cdot r \) (Eq. 1) where:

- \( P \) is mean session arrival rate,
- \( \mu \) is mean duration,
- \( r \) is mean rate.

Packet arrival rate per traffic class: \( \lambda = \frac{T}{s_n} \) (Eq. 2) where \( s \) is packet size.

Delay per traffic class: \( D_n(C) = \frac{\sum_{i=1}^{n} \lambda_i s_i^{(2)}}{2\left(C - \sum_{i=1}^{n} \lambda_i s_i\right)} + \frac{s_n}{C} \) (Eq. 3) where \( C \) is cell capacity.
10. The following condition must be fulfilled: $D_{n_{required}} < D_{n_{measured}}$ (Eq. 4) and $\sum_{i=1}^{n} \lambda_i s_i < C_n$

or $\sum_{i=1}^{n} T_i < C_n$ (Eq. 5), otherwise the HO initiation will be triggered.

11. In order to choose the most suitable cell after the HO process, the measurement matrix from different cells and the traffic class requirements are used. It will be done by applying Fuzzy Multiple Attribute Decision Making (MADM) [Zha04].

12. Observation points are the impact different TLS and the frequency of monitoring, i.e. how frequent the network parameters are calculated.

13. Performance matrix: throughput, delay, rejected users, dropped users, etc....
4.4.3 Simulation flows

Figure 4.3: simulation flow chart

Figure explanation:

- **Admission Control Block:**
  
  Each service request (in WINNER network) will have to go through this process. The session will be served by the suitable BS according to its traffic class, otherwise if the desired BS cannot
support, i.e. due to overload or something else, other supportable WINNER mode will be chosen, if it still not possible, ISHO will be carried on.

• **CELL Block:**

![Diagram of CELL block]

Figure 4.4: The detail of CELL block

Each cell will have its own parameters, i.e. delay and offered traffic, and also active sessions that is divided according to traffic class within that particular cell, which is described in Figure 4.3.

• **TRAFFIC CLASS Block:**

It defines the minimum delay, required rate, packet size, default winner mode, and the arrival rate.

• **Generate Session Block:**

Session arrival rate is defined differently for each traffic class and cell according to already defined parameters in the traffic class block.

• **CALCULATION Block:**

It is already explained in the previous section.

• **HO Trigger Block:**

This block is applied for each cell and traffic class, i.e. there will be 4 fuzzy systems within one cell for each traffic class. It uses fuzzy system with two inputs, *offered traffic and delay*, and the output is HO trigger. Each input has 3 triangle shape membership functions (MF), i.e. low, medium, and high. The membership values vary from zero to the *maximum cell capacity* for the *offered traffic*, and *maximum required delay* of certain traffic class for the *delay*, while the membership degrees vary from 0 to 1. The HO trigger output has 4 triangle shape MF, i.e. No, Probably No (PN), Probably Yes (PY), and Yes. The MF values are normalized, i.e. from 0 to 1, and the degrees also from 0 to 1.

The fuzzy rules of HO trigger are described in the following table:

<table>
<thead>
<tr>
<th>Traffic/Delay</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>No</td>
<td>PN</td>
<td>PY</td>
</tr>
<tr>
<td>Medium</td>
<td>No</td>
<td>PY</td>
<td>Yes</td>
</tr>
<tr>
<td>High</td>
<td>PN</td>
<td>PY</td>
<td>Yes</td>
</tr>
</tbody>
</table>
If the output of the HO Trigger is more than 0.5, the system will go to the HO Decision, i.e. to choose the suitable cell for HO, otherwise there is no HO. Later on, the output of HO Trigger will be used as the input for the HO Accept.

- **HO Decision Block:**

  There are some proposals for the Fuzzy MADM based HO [4,5,6,7]. The differences among them are in the way of weighting different input variables. According to [Nav06], there are several algorithms of Fuzzy MADM based HO in heterogeneous wireless network, i.e. MEW (Multiplicative Exponent Weighting), SAW (Simple Additive Weighting), TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), and GRA (Grey Relational Analysis). The description of SAW can also be found in [Guo06] with the more details explanation on getting the so called weighting vector. In this work, SAW algorithm from [Guo06] is considered for the simplicity. The parameters to be evaluated in are offered traffic, delay, and mean arrival rate.

  This method works as follows:

  1. Define *evaluation matrix* which consist of 3 input parameters:

     $\begin{bmatrix}
     x_{t1} & x_{t2} & x_{t3} & x_{t4} & x_{t5} \\
     x_{d1} & x_{d2} & x_{d3} & x_{d4} & x_{d5} \\
     x_{a1} & x_{a2} & x_{a3} & x_{a4} & x_{a5}
     \end{bmatrix} \quad (\text{Eq. 6})$

     Where element $x_{ij}$ presents the evaluation value of cell $j$ for index $i$ ($i=t, d, a$). Matrix $X$ should be standardized because its elements have no uniform criterion and cannot be compared directly. Set $x_{i\_max} = \max (x_{i1}, \ldots, x_{in})$ and $x_{i\_min} = \min (x_{i1}, \ldots, x_{in})$, and denote $rij$ as the standardized value of $x_{ij}$. Then,

     $\frac{x_{ij}}{x_{i\_max}} (\text{Eq. 7})$

     $\frac{x_{ij}}{x_{i\_min}} (\text{Eq. 8})$

     In this case only, only (Eq. 8) is considered, where $i$ ($i=l, a$) presents the adverse evaluation indices for the after-handoff QoS. Then we get the standardize evaluation matrix $R$ from $X$.

     $\begin{bmatrix}
     r_{l1} & r_{l2} & r_{l3} & r_{l4} & r_{l5} \\
     r_{d1} & r_{d2} & r_{d3} & r_{d4} & r_{d5} \\
     r_{a1} & r_{a2} & r_{a3} & r_{a4} & r_{a5}
     \end{bmatrix} \quad (\text{Eq. 9})$

  2. This algorithm gives a decision according to weighted vectors. Weight vector is defined for the previously described evaluation parameters as $w = [wt, wd, wa]$. Denote quantization value $c_{ij}$ as the relative importance of index $i$ to $j$. Then we get $3\times3$ of contrast matrix $C$. The typical values of $c_{ij}$ are listed in the table below:

<table>
<thead>
<tr>
<th>Importance contrast between $i$ and $j$</th>
<th>$c_{ij}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equally important</td>
<td>1</td>
</tr>
<tr>
<td>Weakly more important than</td>
<td>3</td>
</tr>
<tr>
<td>Strongly more important than</td>
<td>5</td>
</tr>
<tr>
<td>Very strongly more important than</td>
<td>7</td>
</tr>
<tr>
<td>Absolutely strongly more important than</td>
<td>9</td>
</tr>
</tbody>
</table>
Calculate each weight using the geometrical average as

\[ w_i' = \sqrt[5]{\prod_{j=t,d,a} c_{i,j}} (i = t, d, a) \]

Normalize the above weight as

\[ w_i = \frac{w_i'}{\sum_{i=1}^{5} w_i'} (i = t, d, a) \]

3. Consistency check
   a. Compute the maximum eigenvalue \( \lambda_{\text{max}} \) of matrix \( C \)
   b. Compute the consistency index \( CI = (\lambda_{\text{max}} - m)(m-1) \), where \( m \) is the number of parameters
   c. Find the corresponding value random consistency index.
   d. Compute the consistency ratio \( CR = CI/RI \). If \( CR < 0.1 \), matrix \( C \) can be accepted; otherwise, adjust matrix \( C \) and go to step 1).

4. Fuzzy integration decision
   Optimum cell, \( \text{cell}_{\text{best}} \), is selected as:
   \[ \text{cell}_{\text{best}} = \max \{ v(w_i' \cdot r_{ij}) \} \]

   - **HO Accept Block**
     This block is meant to evaluate if the selected RAN is able to accept the HO session with the required QoS. It is also applied for each cell and traffic class. The inputs are the \( \text{HO trigger} \) of the \textit{current cell}, and \textit{offered traffic and delay} of the \textit{target cell}. The output of this will be “Yes” or “No”. If the output is “Yes” then the session HO to the selected cell is carried out, otherwise it will stay at the current cell.

Simulation flows explanation:
- Simulation is done each iteration which is equivalent with 1 s.
- Session is generated in each RAN. For the WINNER RAN, admission control will be applied.
- Calculation is done in each cell afterwards.
- Fuzzy inference system will take the calculation of those parameters as inputs for triggering HO
- When the HO is triggered, the Fuzzy MODM will be applied to choose the suitable target cell.
- Update the session, i.e. increase the time stamp, remove the session from “active_sesession” matrix if it reaches the end of duration or if it is being handover to other cell, add the handover session to new cell’s “active_sesession” matrix.
5. References


[Win44] IST-WINNER D4.4


[Umt] UMTS forum magic mobile