A Power Efficient RAT Selection Algorithm for Heterogeneous Wireless Networks

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Abstract—**The Fourth Generation of wireless network (4G) is a heterogeneous network where different Radio Access Technologies (RATs) are integrated. This requires a need for Common Radio Resource Management (CRRM) to support efficient utilization of radio resources and to provide the required Quality of Service (QoS) for allocated calls. RAT selection algorithms are an important part of CRRM. This paper proposes an intelligent hybrid power efficient RAT selection algorithm (patent pending[1]). It is a battery power saver algorithm which includes sorting available RATs, collecting information on each RAT using the IEEE P1900.4 Protocol, and making decisions for selecting the most suitable RAT for incoming calls. The proposed power efficient algorithm is compared to centralized and distributed algorithms in terms of new call blocking and Vertical Handover (VHO) call dropping probabilities. Users' satisfactions probability and saving battery power percentage are also compared. Simulation results show that the proposed algorithm performs better than the centralized and distributed algorithms in terms of blocking, dropping and users' satisfactions probabilities. The proposed and the distributed algorithms have similar performance in term of saving battery power, and both perform better than the centralized algorithm.**

Keywords- Heterogeneous Wireless Network; Common Radio Resource Management (CRRM); Radio Access Technology (RAT) Selection Algorithms; Power Efficient Algorithm.

I. INTRODUCTION

Next Generation Wireless Network (NGWN) will combine different Radio Access Technologies (RATs) such as UMTS Terrestrial Radio Access Network (UTRAN), Long Term Evolution (LTE) and Wireless Local Area Network (WLAN) where User Terminals (UTs) will have the ability to communicate through one of the available RATs [1-3]. A major challenge is how the users will be allocated to the most suitable RAT for them.

Common Radio Resource Management (CRRM) has been proposed to manage radio resource utilization in heterogeneous wireless networks [4-5]. RAT selection algorithms are part of the CRRM algorithms. Simply, their role is to verify if an incoming call will be suitable to fit into a heterogeneous wireless network, and to decide which of the available RATs is most suitable to fit the need of the incoming call and admit it.

A number of RAT selection algorithms have been proposed in the literature [6-7]. These algorithms can be categorized into network centric or user centric RAT selection algorithms. Network centric algorithms have the benefit of considering more criteria in the decision making process; however, they do not consider users' preference and they do not guarantee required Quality of Service (QoS) for all admitted calls. User centric algorithms have the benefit of considering users' preferences; however, they do not take into account the network benefits and policies and they may lead to high blocking and dropping probabilities. All proposed algorithms have limitations and significant shortcomings.

In this paper, a new RAT selection algorithm, which addresses the users' preferences and at the same time considers the network policies and improves the efficiency of radio resource utilization, is proposed. The proposed algorithm targets users that prefer to save power when they are running out of battery which will allow them to be connected for more time. More details on this algorithm are available in Section II. The proposed algorithm aims to balance between users' requirements and preferences and network factors and polices.

The rest of the paper is organized as follows. In Section II, we describe the proposed intelligent power efficient RAT selection algorithm. Section III presents the cost function model for the proposed algorithm. In Section IV, we compare the performance of the proposed algorithms against the centralized and distributed algorithms in terms of new call blocking probability, VHO calls dropping probability, users' satisfactions probability and saving battery power percentage. The three algorithms are simulated in a scenario in which UTRAN, LTE and WLAN are overlapped in the same geographical area. Results are presented in the same section. Finally, Section V concludes this paper.

II. PROPOSED INTELLIGENT POWER EFFICIENT RAT SELECTION ALGORITHM

Centralized RAT selection algorithms do not guarantee the required QoS for the admitted calls, and reduce the network capacity. Distributed RAT selection algorithms do not consider network preferences and policies. In this section, we propose an intelligent hybrid RAT selection algorithm for power

[1] The substance of this paper is subject to an Australian patent application filled by the University of Technology, Sydney (UTS).

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efficiency which is based on terminal controlled with network assistance using the IEEE P1900.4 Protocol [8] to enable the communication between the UTs and the different wireless networks.

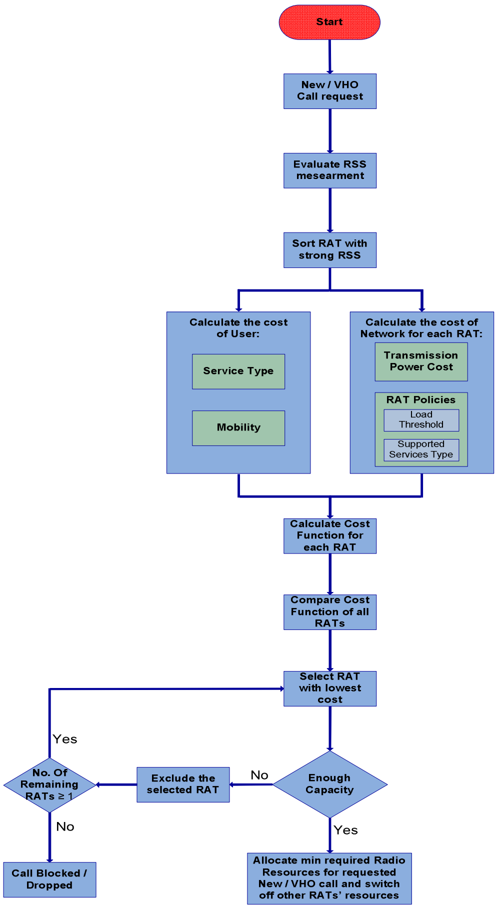

Figure 1. An intelligent power efficient RAT selection algorithm.

Fig. 1 represents the flow chart of the intelligent hybrid RAT selection approach for power efficiency. When a new or VHO call is requested, UT will first evaluate the Received Signal Strength (RSS) measurements and makes a list of available RATs that have a strong RSS to accommodate the requested call. Then, UT will collect information on each RAT using the IEEE P1900.4 Protocol. These information will cover transmission power cost (low, medium or high) of each RAT and RAT policies attributes such as supported services type and load threshold for new and VHO calls. A cost will be given for each attribute for each RAT. Other costs will be given for the user attributes (requested service type and user mobility status). After that, the cost function of each RAT will be calculated. Then, a comparison between these costs is made. The RAT with the lowest cost of allocation will be selected for the requested call. A minimum amount of required radio resources will be allocated from the selected RAT for the requested call. Then, the other RATs' resources (e.g. antenna, transmitter, receiver, Analog-to-Digital Converters (ADC), etc.) in the UT will be switched off. If the selected RAT does not have enough capacity to allocate the requested call, another RAT will be selected. If none of the available RAT has enough capacity to serve the requested call, the call will be dropped or blocked.

III. A Cost Fuunction Model for the Power Efficient Algorithm

The cost function for the allocation of radio resources to the requested user calls in heterogeneous wireless networks is presented in this section. Calls will be allocated to the RAT that has the lowest cost. If the selected RAT is unable to serve a call, another RAT will be selected. If none of the RATs are able to serve the call, it will be blocked / dropped. The cost of allocation of each RAT is calculated by the following equation:

$$C = C_N + C_U \ , \tag{1}$$

where

- C is the cost function for the allocation of radio resources.
    - C_N is the cost of network.
    - C_U is the cost of user.

The cost of network for the power efficient algorithm is calculated as follows:

$$C_N = \frac{\sum_{j=1}^{N} (W_j \times P_j)}{\sum_{j=1}^{N} W_j} \ , \tag{2}$$

where

- P_j is the parameter related to allocation of resources in the network, such as: transmission power cost (P_{TP}), supported service type cost (P_{SST}) and load threshold cost (P_{LTH}).
- W_j is the factor weight for each network parameter cost, such as: transmission power weight (W_{TP}), supported service type weight (W_{SST}) and load threshold weight (W_{LTH}).

By adding the above parameters and weight factors, Equation (2) will be:

$$C_N = \frac{W_{TP} \times P_{TP} + W_{SST} \times P_{SST} + W_{LTH} \times P_{LTH}}{W_{TP} + W_{SST} + W_{LTH}} \ , \tag{3}$$

The cost of user for the power efficient algorithm is calculated as follows:

$$C_U = \frac{\sum_{i=1}^{N} (W_i \times P_i)}{\sum_{i=1}^{N} W_i} \ , \tag{4}$$

where

- P_i is the parameter related to the usage of resources depending on user status, such as: requested service type cost (P_{RST}) and cost of mobility (P_M).
- W_i is the factor weight for each user parameter cost, such as: requested service type weight (W_{RST}) and mobility weight (W_M).

By adding the above parameters and weight factors, Equation (4) will be:

$$C_U = \frac{W_{RST} \times P_{RST} + W_M \times P_M}{W_{RST} + W_M}, \quad (5)$$

The weights for network parameter costs and user parameter costs are assumed based on need of different applications in each scenario and the practical implication of that scenario.

IV. SIMULATION AND RESULT

In this section, we will compare the proposed power efficient algorithm with the centralized and the distributed algorithms.

In the centralized algorithm, a load-balancing algorithm is selected. It aims to distribute traffic load between all available RATs in a heterogeneous wireless network. Balancing load between all available RATs in a heterogeneous wireless network offers an efficient utilization of the radio resources [9-11]. In the centralized load-balancing algorithm, calls are allocated to the RAT that has the minimum load which is based on the decision made by the core network or the base station.

In the distributed algorithm, the RAT selection decision is made by the UT, where the users preferring to save power select the RAT that offers the lowest transmission power without considering any of the network factors such as network capacity, coverage area and supported service type for the selected RAT.

The proposed power efficient algorithm aims to increase users' satisfactions by allocating users that prefer to save power when they are running out of battery to a RAT that offers them less transmission power and at the same time, it aims to improve the efficiently of radio resource utilization by minimizing unnecessary handover. More details on this algorithm are available in Section II.

A. Simulation Scenario

The comparison for the performance of centralized, distributed and the proposed power efficient algorithms is simulated in a scenario which is assumed that UTRAN, LTE and WLAN are overlapped in the same geographical area. The area which has coverage for the three RATs is named: hotspot area. It is assumed that users arrive and can move inside or outside the hotspot area. Three different service types are considered: voice, data and video calls. Two different video call types are considered: video calls with low resolution and video calls with high resolution (video conference calls). It is assumed that the calls arrivals are generated according to a Poisson process with a mean rate of λ [12]. It is also assumed that each call is held for an exponentially distributed call duration time with a mean of $1/\mu$ [12]. See reference [13] by AL Sabbagh et al. for more details about the simulation scenario.

B. Evaluation of Power Consumption

Transmission power cost is one of main parameters of the proposed power efficient algorithm. Different amounts of transmission power are required by the UT to communicate with the base station/access point which depends on the UT location and the RAT that will be connected to. The energy consumption for the three RATs (UTRAN, LTE and WLAN) is evaluated in this subsection.

As battery power in the UT is the crucial parameter, transmission from UT to base station is considered. Not the other way around. It is also assumed that the dominant power consumption in the UT is for signal transmission. The transmit power of UT is calculating using the Friis transmission equation [14] as follows:

$$\frac{P_R}{P_T} = G_T \times G_R \times \left(\frac{\lambda}{4\pi d}\right)^2, \quad (6)$$

where

- P_T is the transmission power.
- P_R is the receiver power.
- G_T is the transmitter antenna gain.
- G_R is the receiver antenna gain.
- λ is the wavelength of the transmitted signal.
- d_k is the distance between the transmitter and the receiver.

Using the above equation, the transmit power will be:

$$P_T = \frac{P_R \times (4\pi d)^2}{G_T \times G_R \times \lambda^2}, \quad (7)$$

It is assumed that the total number of bits required for the requested service is same for all RATs; energy per bit at the receiver is the same. The total energy per second is:

$$E_{TOT} = E_b \times br, \quad (8)$$

where E_b is the signal energy per bit and br is the bit rate.

Therefore, the total power into a receiver at the base station/access point is equal to the total energy per second.

The wavelength of the transmitted signal is:

$$\lambda = \frac{c}{f}, \quad (9)$$

where c is the speed of light in free space and f is the wave's frequency.

Ahead of the receiver is an antenna and feed system which has gain and efficiency which includes a collection of factors such as: amplifier efficiency, antenna coupling efficiency and general circuit efficiency factors. It is estimated for each RAT. At the UT, the power from the power amplifier feeds an antenna system which likewise has gain and efficiency. A list of other parameters and assumptions for the three networks are shown in Table I.

TABLE I
TRANSMIT POWER PARAMETERS

Parameter	UTRAN	LTE	WLAN
Average Distance between UT and Base Station	500 m	500 m	100 m
RAT Efficiency Factor	0.2	0.3	0.15
RAT Antenna Gain	18 dBi	18 dBi	6 dBi
UT Antenna Gain	0 dBi	0 dBi	0 dBi

The energy required at the UT transmitter to achieve a particular receive energy will then be proportional to the square of the distance. By using the above equations, the nominal transmit power of UT to each RAT is calculated by the following equation:

$$TP_k = \frac{E_b \times br_k \times f^2{}_k \times (4\pi d)^2}{G_T \times F_T \times G_k \times F_k \times c^2}, \qquad (10)$$

where

- br_k is the bit rate of RAT k.
- f_k is the frequency of RAT k.
- d_k is the distance between UT and the base station or the access point of RAT k.
- F_T is the transmitter efficiency factor for the UT.
- G_k is the antenna gain for RAT k.
- F_k is the efficiency factor for RAT k.

For comparison purposes, the data on Table 2 in reference [15] by researchers at Ericsson and TeliaSonera was used for the average transmission power of voice, data and video calls in UTRAN to generate the following results.

C. Simulation Results

A comparison for the performance of centralized, distributed and the proposed power efficient algorithms in terms of new calls blocking probability, VHO calls dropping probability, users' satisfactions probability and saving battery power percentage is presented in this subsection.

Figure 2 and Figure 3 show the blocking and the dropping probabilities for the three RAT selection algorithms. Blocking and dropping probabilities are calculated as follows:

$$P_{bloc} = \frac{N_{bloc}}{N_{New}}, \qquad (11)$$

where

- N_{bloc} is the number of blocked new calls.
- N_{New} is the total number of requested new calls.

$$P_{drop} = \frac{N_{drop}}{N_{VHO}}, \qquad (12)$$

where

- N_{drop} is the number of dropped VHO calls.
- N_{VHO} is the total number of requested VHO calls.

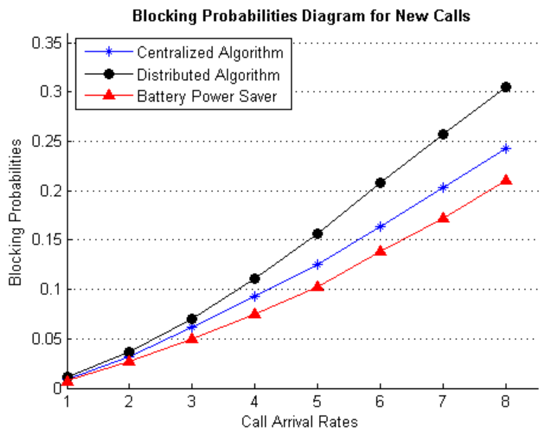

Figure 2. New calls blocking probability.

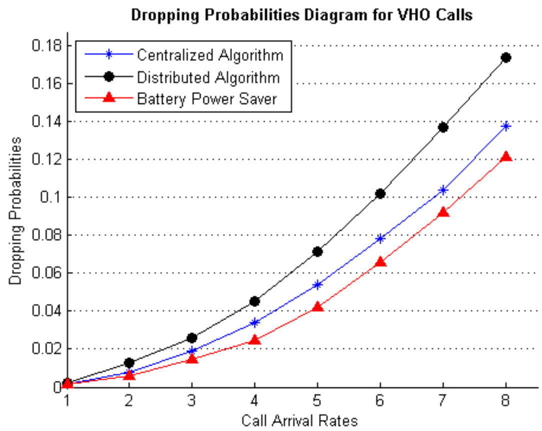

Figure 3. VHO calls dropping probability.

It can be seen that the proposed algorithm outperforms the centralized and distributed algorithms in term of blocking and dropping probabilities. The proposed algorithm performs better than the centralized algorithm because the centralized algorithm leads to high levels of unnecessary VHO which reduces the overall network capacity. In addition, the network capacity is reduced in centralized algorithm as a result of the signaling load and delays introduced by the communication between the network entities during the RAT decision process. Distributed algorithm shows the lowest levels of performance when compared to the other two algorithms. This is because the distributed algorithm does not consider any of the network factors such as load threshold.

Figure 4 shows the users' satisfactions probability for the three RAT selection algorithms. The users' satisfactions probability is calculated by the following equation:

$$P_S = \frac{N_{S\_New} + N_{S\_VHO}}{N_{New} + N_{VHO}}, \qquad (13)$$

where

- N_{S_New} is the number of satisfied new call users.
- N_{S_VHO} is the number of satisfied VHO call users.

User is indicated as a satisfied user if the user prefers to save power and has been allocated to a RAT that offers the lowest transmission power between the available RATs when requesting new or VHO call.

This figure shows that the distributed and the proposed algorithms perform better than the centralized algorithm. This is because, both proposed and distributed algorithms consider users' preferences which increase their satisfactions. Distributed and proposed algorithms have similar performance when traffic level is low. However, when the traffic becomes high, the proposed algorithm outperforms the distributed algorithm in term of users' satisfactions probability. This is because that the distributed algorithm does not consider any of the network factors such as load threshold.

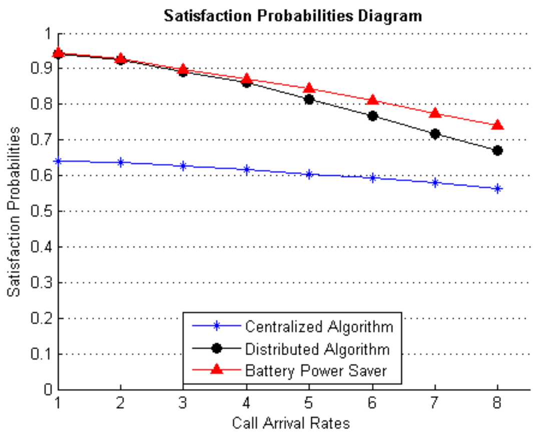

Figure 4. Users' satisfactions probability.

Figure 5 illustrates the average satisfaction percentage increase for the proposed algorithm compared with the centralized and the distributed algorithms. Average satisfaction increasing percentages are calculated by subtracting the users' satisfactions probability of the centralized and distributed algorithms from the users' satisfactions probability of the proposed algorithm. This figure shows that the users' satisfactions have been increased around 30% against the centralized algorithm when traffic load is low and around 18% when traffic load is high. It also shows that the users' satisfactions percentages for the proposed algorithm are similar to the distributed algorithm when traffic load is low; however, users' satisfactions have been increased around 7% when traffic load is high.

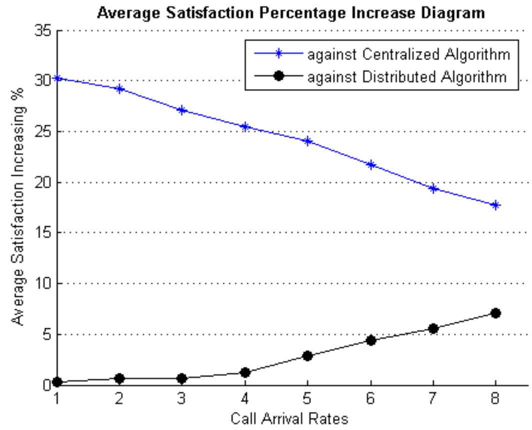

Figure 5. Average satisfaction percentage increase.

Figure 6 shows the average transmission power per call of UTs that prefer to save battery power for the three RAT selection algorithms. Simulation results show that the distributed and the proposed algorithms perform better than the centralized algorithm. This is because the centralized algorithm does not consider users' preferences. Distributed algorithm allocates calls to the RAT that offers the lowest transmission power to the UT device. The proposed algorithm considers users' preferences and at the same time, it balances between these preferences and the network factors such as supported service type and load threshold. The proposed and the distributed algorithms have similar performance in term of saving battery power.

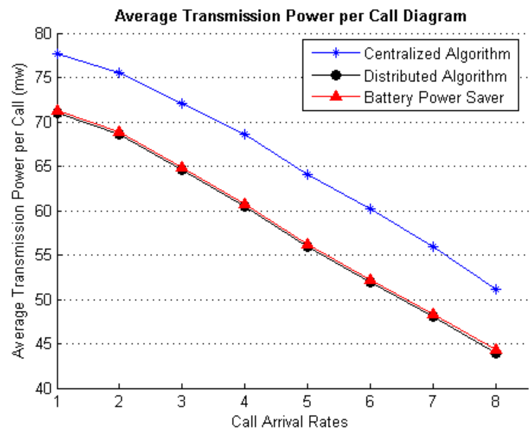

Figure 6. Average transmission power per call.

Figure 7 shows the average saved battery power percentages per call of UTs that prefer to save battery power for the proposed algorithm compared with the centralized

RAT selection algorithms. The average saved battery power percentage is calculated as follows:

$$SB_{Percentage} = \frac{TP_{Cen} - TP_{Prop}}{TP_{Prop}}, \qquad (14)$$

where

- TP_{Cen} is the average transmission power per call for the centralized algorithm.
- TP_{Prop} is the average transmission power per call for the proposed algorithm.

This figure shows that users which prefer to save battery power can save between 9% – 16 % per call in the proposed algorithm compared to the centralized RAT selection algorithm.

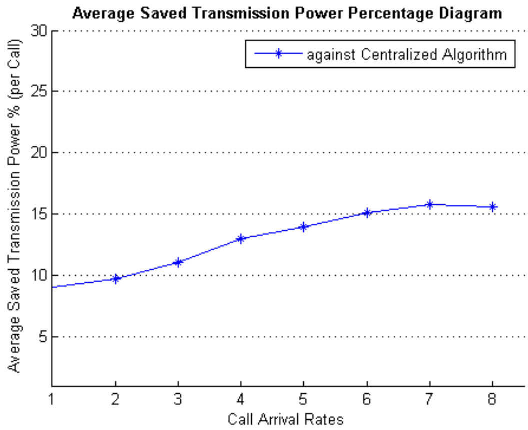

Figure 7. Average saved transmission power percentage per call.

V. CONCLUSION

A multimode UT has the capability to select the RAT that suits its requirements. In this paper, we propose an intelligent power efficient RAT selection algorithm which aims to increase users' satisfactions by allocating users that prefer to save power when they are running out of battery to a RAT that offers them less transmission power and at the same time, improve the efficiently of radio resource utilization. The proposed algorithm is compared with the centralized and the distributed algorithms in terms of new call blocking, VHO call dropping and users' satisfactions probabilities and saving battery power percentage. Simulation results show that the proposed algorithm is more efficient in terms of blocking, dropping and users' satisfactions probabilities and saving battery power percentage. The proposed and the distributed algorithms have similar performance in term of saving battery power percentage.

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