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A Discrete Event Framework for OFDMA Relay-Based Cellular Networks

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ABSTRACT

The cooperation of Relay-Based Cellular Network (RBCN) and Orthogonal Frequency-Division Multiple Access (OFDMA) techniques provide rich of promising solutions especially in terms of Radio Resource Management (RRM). However, the main challenge of this cooperation is managing the resources in a dynamic system in the midst of co-channel interference. Allocating of the RRM associated schemes have been developed to overcome these interferences and to operate the relays in a dynamic and opportunistic manner. The deployments of these RRM schemes have enormous matrices of combination analyzing these performances are of vital essence. There are different simulator tools to address these needs such as NS2, OPNet, OMNet++, etc. An effort to enrich these repositories of simulators is to provide a discrete customization of analyzing the main aim of the study. A discrete event simulation for RBCN evaluation using a general-purpose programming language has been solved. The performance analysis orientation is on Signal-to Interference-plus-Noise Ratio (SINR) algorithm with specific focus on the transmission reliability of relays for channel fading in terms of spectral efficiency for downlink of OFDMA relay-based cellular networks. The developed simulator has been extensively tested and has proven to be a valid and substantial simulator.

Key words: Discrete event simulation, scheduling, queuing, performance modeling

INTRODUCTION

Wireless networks development has created many issues especially pertaining the design of networks for that pure optimization of resources. The merging of Wireless Cellular Network (WCN) and Wireless Multihop Network (WMN) to cater these issues has resulted in the relay nodes to enhance the quality of the end-to-end communication. The integration of relay nodes has been proven more cost effective in comparison to adding the total numbers of Base Station (BS) in the effort to have better coverage.

In the designing of wireless networks, there are three main phases which are; mathematical analysis, simulation and monitoring of an actual network (Zola *et al*., 2010). Mathematical analysis is for deriving the numerical results and attempts to find analytical solutions to problems by using hypothesis models. Next is the simulation method which can be used to realize the structure of the model, analyze system performance and produce dynamic network behaviors. Monitoring of the performance in an actual network or comparing multiple alternatives over a wide range of conditions has proven to be a valuable tool in many areas where required analytical methods are not applicable and experimentation is not feasible (Mehta *et al*., 2010). The results reflect the actual network assumptions in close proximity (Zola *et al*., 2010). A suitable simulation model will be based on extracting the relevant procedures and parameters from the real system that have an impact on the outcome (Law, 2007). Therefore, the entities of the simulation are the real system (i.e., source of raw data), the conceptual model (i.e., set of instructions for data generating) and the simulator (i.e., device for carrying out model instructions) (Law, 2007).

One of the criteria to classify simulation models is based on the time characteristic which is shown in Fig. 1 (Law, 2007). The deterministic classification is a rule-based simulation and this simulation model does not contain random attributes. Stochastic simulations are based on the conditional probabilities and produce output that is random. Static simulations are not based on the time sequence of changes. It represents the system at a particular time. However, dynamic simulations represent the system as it evolves over time. Therefore, it updates each entity at each occurring event such as the conveyor system in a factory. The Continues state of the system involves a system which continuously changing over time. However, the discrete simulations manage the event at particulars points in time. Thus, the state of the system will change instantaneously at random points in time because of the occurrence of a discrete event. Hybrid simulations are combinations of continues and discrete event simulation.

In wireless network most of the simulators are based on the discrete event simulation (Zola *et al*., 2010; Mehta *et al*., 2010) which there would be a list of events, where an event is defined as an instantaneous occurrence that may change the state of the system while the events are processed in order. In the wireless network some state variables are random (stochastic), time evolution is important (dynamic) and significant changes occur in discrete time instances (discrete event). There have been many simulators for studying the performance of mobile and fixed communication networks. Among them dominantly used are NS-2, GloMoSim, J-Sim, OMNet++, OPNet etc. However, none of these has analysis and implementation of sub-channels or to model an explicit packet detection and timing synchronization phase (Riley, 2003). In this case, MATLAB and Monte Carlo simulations are widely used simulators especially for the RBCN analysis (Riley, 2003).

The motivation of using General Purpose Language (GPL) such as C, C++, Fortran and building a simulator from scratch was to allow customization requirements of researches within the area of RBCN and to contribute towards the spectrum of analysis too. Moreover, using GPL

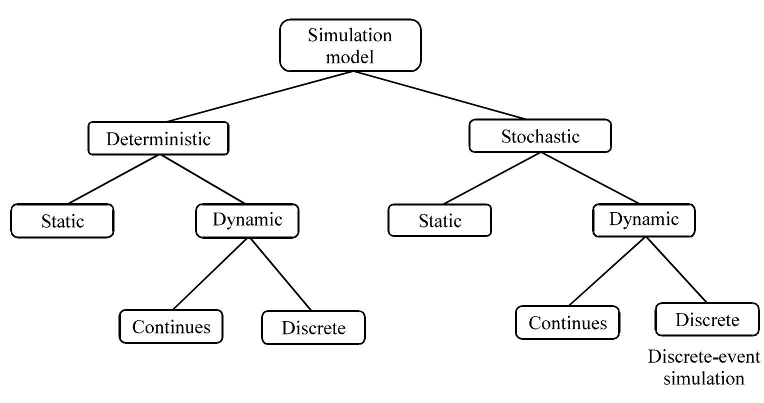

Fig. 1: Classification of simulation models 3 (Law, 2007)

simulations includes the essential assumptions for inclusion of the required parameters or functions for any study (Al-Sanabani *et al.*, 2008). The GPL simulations which are specific in functionality but versatile in enhancement are producing the maximum conceivable performance, level especially in terms of consuming run time. Thus, the advantage of developing a simulator from the scratch is to offer freedom to understand, construct protocol modules, develop customized topologies, specifies the routing of the Mobile Stations (MSs) and to plot the necessary performance graphs (Al-Sanabani *et al.*, 2008).

In this study, the simulation for the RBCN using GPL and the system performance was validated by the comparison of the performance metrics of the SINR algorithms have developed while studying the transmission reliability of relays for channel fading in terms of spectral efficiency for downlink of OFDMA Relay-Based Cellular Networks.

The presence of some survey and case study (Zola *et al.*, 2010; Mehta *et al.*, 2010) in which to find a wireless network simulator that offers a good balance between the availability of ready to use models, scripting and language support, extendibility, graphical support, ease of use etc. In (Mehta *et al.*, 2010) most widely simulators are compared in terms of their advantages and disadvantages based on different studies and surveys for next generation networks. Zola *et al.* (2010) presented discrete-event simulation of wireless network. However, there is no study presented different types of simulation for RBCN. The review of the studies (Oyman, 2010; Zhang *et al.*, 2012a, b; Calcev and Bonta, 2009; Calvo *et al.*, 2009; Hossain and Mammela, 2009; Venkatasubramanian and Haustein, 2012; Ahn and Kim, 2008; Liu *et al.*, 2010b; Chen *et al.*, 2009; Huang *et al.*, 2007; Georgiev and Dimitrova, 2010; Lin and Yu, 2012) in the RBCN focuses on analytical solutions/numerical and empirical studies/simulation in a combined manner while they developed a different algorithm to improve the performance of the entire system, mostly system throughput. It is often difficult to decide which simulator to select for a specific task, especially for RBCN. However, there are three types of simulation which is widely used for RBCN which are the Monte Carlo, MATLAB and discrete event using GPL performance. Table 1 summarizes the different RRM scheduling and the simulation technique, used for these analyses.

The (Oyman, 2010; Zhang *et al.*, 2012b; Calcev and Bonta, 2009; Vanganuru *et al.*, 2011; Mei *et al.*, 2010) using Monte Carlo simulation to simulate their system model. On the other hand, the (Calcev and Bonta, 2009; Calvo *et al.*, 2009; Hossain and Mammela, 2009; Venkatasubramanian and Haustein, 2012; Salem *et al.*, 2010) are using MATLAB as their simulator.

In contrast, discrete event simulation is discrete dynamic stochastic simulation model that is highly used by researchers in the area of cellular features, mobility, handoff and traffic problems (Zola *et al.*, 2010). This simulation is based on the arrival of traffic (e.g., voice or data calls, packets, messages, etc.) into the network and the departure of these traffic. There is no specific release and new feature of discrete event simulation using GPL; therefore, it can be easily run on any system. Monte Carlo simulation represents the system in a particular time and the result cannot be near to actual network in constant with discrete event simulation.

However, Ahn and Kim (2008), Chen *et al.* (2009), Huang *et al.* (2007), Georgiev and Dimitrova (2010), Zhang *et al.* (2012a), Lin and Yu (2012), Mei *et al.* (2010), Salem *et al.* (2010), Kim and Lee (2012), Bi *et al.* (2011), Joung and Sun (2012), Salem *et al.* (2009) and Liu *et al.* (2010a, b) using GPL to develop their network model, none of them presented the system in logic and explained how they translate it to simulation.

Table 1: Summarize the different RRM scheduling

Algorithm name	Analytical solution/ numerical	Empirical studies/ simulation	Simulation package	Performance metrics	Authors
Maximum Signal-to Interference-plus-Noise Ratio (Max SINR)	✓	✓	Monte Carlo	Spectral efficiency	Oyman (2010)
Helper selection	NA	✓	Monte Carlo	Mean cell throughput	Vanganuru *et al*. (2011)
Channel Correlation based User Selection (CCUS) algorithm	✓	✓	Monte Carlo	Sum rate, outage probability	Zhang *et al*. (2012b)
Potential Utility Comparison based Cooperative Pilot Power Control Algorithm (PUC-CPPCA)	NA	✓	Monte Carlo	Service request block rate	Mei *et al*. (2010)
Opportunistic relaying	✓	✓	Monte Carlo, MATLAB	Coverage extension, throughput, spectrum efficiency	Calcev and Bonta (2009)
Fairness-aware joint routing and scheduling	NA	✓	MATLAB	Average throughput	Salem *et al*. (2010)
Global optimization algorithm, sequential optimization algorithm	✓	✓	MATLAB	Network utility, throughput-fairness tradeoffs	Calvo *et al*. (2009)
Per-hop based multihop scheduling algorithm	✓	✓	MATLAB	System delay, system throughput	Hossain and Mammela (2009)
Cell-guaranteed bit rate by relay scheduling (cell-GBRS)	✓	✓	MATLAB	Received power	Venkatasubramanian and Haustein (2012)
Proportional Fair (PF)	✓	✓	GPL	PF metric, Jain fairness index	Ahn and Kim (2008)
Optimal opportunistic resource scheduling algorithm	✓	NA	GPL	Average data rate	Kim and Lee (2012)
Relaxed-TDMA	✓	NA	GPL	Outage probability	Bi *et al*. (2011)
OFTT protocol	✓	NA	GPL	Power efficiency	Joung and Sun (2012)
Novel three-time-slot TDD transmission protocol	✓	✓	GPL	Sum rate	Liu *et al*. (2010b)
Fairness-aware radio resource management	✓	NA	GPL	Average throughput	Salem *et al*. (2009)
Dirty Paper Coding (DPC)	✓	✓	GPL	Spectral efficiency	Chen *et al*. (2009)
Heuristic algorithm, iterative power allocation algorithm	✓	✓	GPL	System capacity	Huang *et al*. (2007)
Weighted Proportional Fairness (WPF) scheduling algorithm	NA	✓	GPL	Cell-edge UEs, cell throughput	Liu *et al*. (2010a)
One-By-One (OBO) scheduler	✓	✓	GPL	Effective rates, throughput	Georgiev and Dimitrova (2010)
Dual based algorithm	✓	✓	GPL	Sum rate	Zhang *et al*. (2012a)
Heuristic-efficient scheduling and resource allocation algorithm	✓	✓	GPL	Cumulative distribution, utility	Lin and Yu (2012)

NA: Not available

The need for low computation, specifically tailored for RBCN and the ability to add new modules easily has motivated the need for the proposed and developed simulator.

PROPOSED RBCN DISCRETE EVENT SIMULATION FRAMEWORK

The proposed simulation framework of RBCN depends on the inputs and parameters that characterize the scenario to be evaluated. This includes the number and location of BSs, RSs, MSs and the specific parameters of the algorithm. The output of the simulation framework provides some performance that allows the comparison among the different algorithms. The mechanism of these algorithms is depended on the network model, mobility model, traffic model and service requirements. The network model is used to specify the network settings, the configuration of the cell and the layout to be studied as defined in the scenario planning. The mobility model allows to specify the initially scattered and the movement of MSs and traffic model is depending on the traffic generation process which is involve in the starting and ending of MSs' calls and simulated and multimedia services with different requirements and purpose.

Network model: We consider a downlink model of relay-based multi-cellular network (Oyman, 2010), with a center cell surrounded by six interfering cells. The radius of all cells, D, are the same in hexagonal shape. The global frequency reuse is assumed across all cells to maximize spectrum utilization. Each cell has one BS in the middle which is responsible for connection setup and scheduling packets and M (i.e., six) RSs with radius R and angular $2\pi/M$ from the BS. There is no sectorization in all cells, thus, omnidirectional antennas are assumed for the BSs and RSs to process. There are two types of users; Near user (N) indexed by $n = 0, \dots, N$ located with the radius of D_n from BSs which have a strong link quality from the BS and directly communicate with BS and Far user (F) indexed by $f = 0, \dots, F$ which have a poor link quality from the BS located at the cell edge and communicate with the BS via., RS over two hop routing. The role of the RSs is to enhance the end-to-end link quality communication, thus, the BSs send the packets to the relative RSs and RSs decode and re-encodes and forwards the packet to the MS. The selections of RS/BS for MSs are based on the shortest path principle; i.e., the MSs are connected to the nearest BS/RS. The network model is shown in Fig. 2.

Time division based on half duplex is assumed. Thus, indicating that the terminals are unable to transmit and receive at the same time. The channel links are assumed to be independent for all links to/from near and far users and all links over the wireless backhaul among BSs and RSs. The transmission occurs over all of the three links:

- $\mathbf{L_{BR}}$: The link between the BS and RS
- $\mathbf{L_{BN}}$: A link between the BS and Near MS
- $\mathbf{L_{RF}}$: A link between RS and Far user

Positive time-sharing coefficients are assigned to the links; β_B, β_F and β_N to links L_{BR}, L_{RF} and L_{BN} such as $\beta_B+\beta_F+\beta_N = 1$.

The system has happened in two time slots; (1) The time that the L_{BR} link is active (β_B) and (2) The time that the L_{BN} and L_{RF} links ($\beta_{NF} = \beta_F+\beta_N$) are simultaneously active such that $\beta_B+\beta_{NF} = 1$.

In the first time slot, the BSs send the data to the RSs and in the second time slot the BSs and RSs send data to the MSs simultaneously.

Mobility model: Mobility model is used to represent the movement of the MSs and their placement. In this study, near and far users are randomly located in the system, near users randomly in the center with the radius of D_n from BS and far users randomly located at the cell

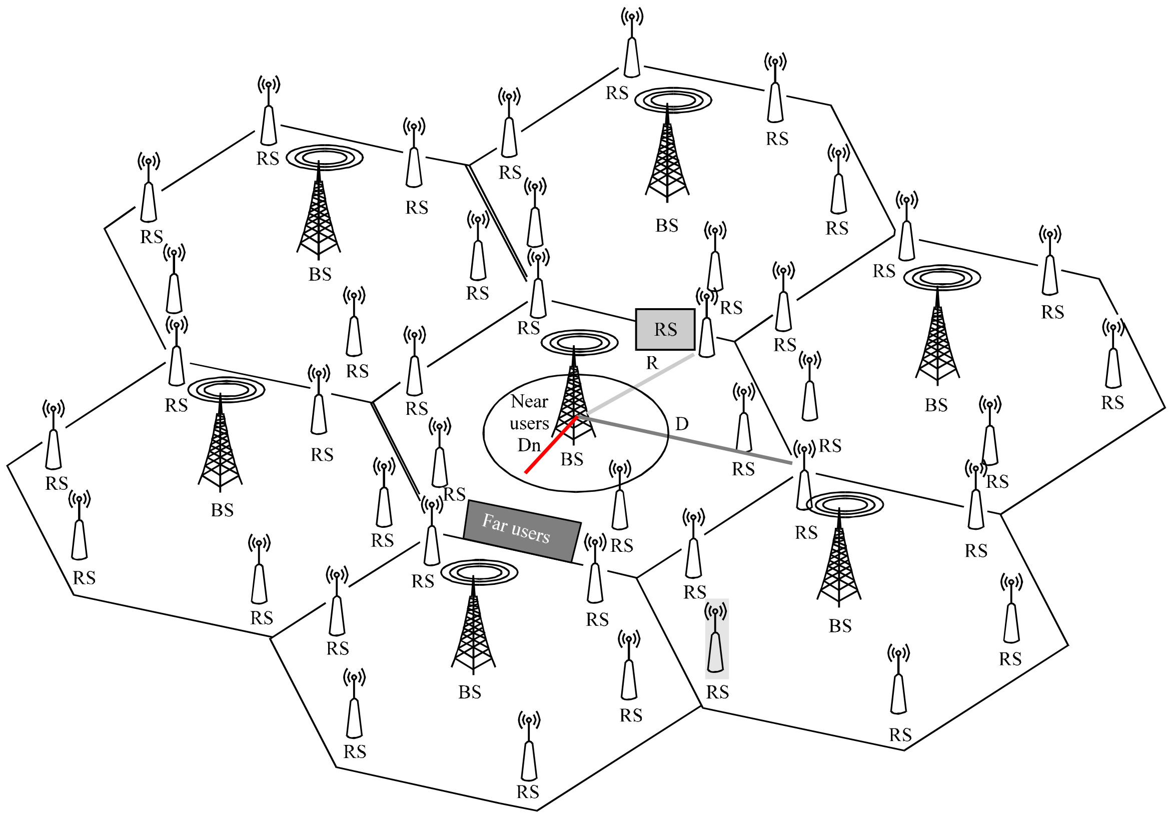

Fig. 2: RBCN network model

edge. The network entry and handoff management of the MSs are based on the shortest path principle. The dynamically changing link conditions of the far and near users are sending by the MSs through channel quality feedback mechanisms.

Traffic model: A traffic generation model in this system is based on the Poisson process with average rate λ, in which the number of received calls request of MSs or packets per time unit follows the Poisson distribution. Same arrival rate is assumed for all the cells.

Simulation framework: Figure 3 shows the simulation framework which is proposed for the RBCN and the associated analysis with respected to our network model, mobility model and traffic model. The figure illustrates the scheduling framework for one BS and its related RS. Both far and near data arrive to the BSs and data schedule base on their arrival time. We consider three scheduling section. First scheduling happens in BSs for schedule next arrival, separating the near and far data and send the far data to their related RSs. A second scheduling also happen in BSs to schedule the data to send it to near user and find the best user among the users to take the data. The third scheduler is working same as the second scheduler but for far data and users. The far data will send to the related RSs in the first time slot. The system is translated in queue theory, therefore the near and far data will be waiting in their related queues and scheduled in the second time slot. The near users will be scheduled in the BSs based on their link quality while the far users schedule in the RSs base on their link quality simultaneously. After the downlink resource allocation, the near and far users send the channel quality feedbacks to their related BS/RS.

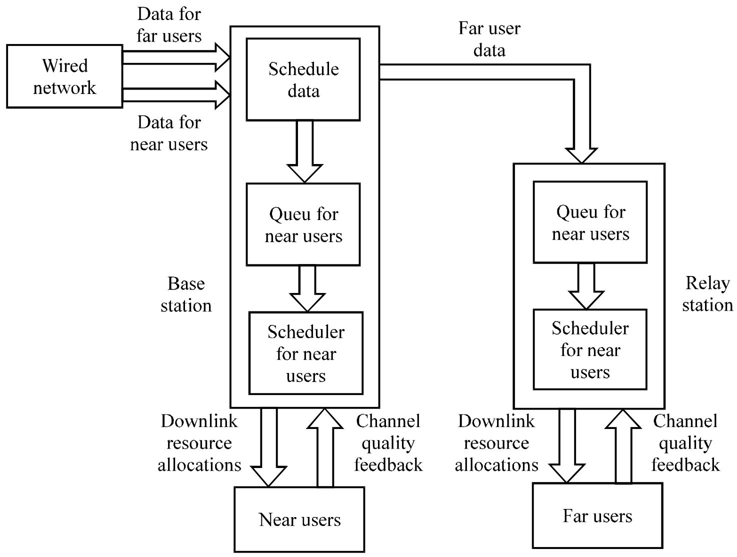

Fig. 3: Simulation framework

Simulation model: The simulation model which was developed to reflect the system in the easiest way for better understanding is demonstrated how the links are connected to the RSs/MSs and where the queue manage to keep the data is shown in the Fig. 4. Based on the network model (i.e., Fig. 2) we have one BS for each cell and six surrounded RSs with two types of MSs. There is one queue for the all Near MSs and one queue for all Far RS. Each RS has its own queue for its all Far MSs. In the first time slot, the link L_{BR} will be active and the BS send the far data to the related RSs (RSs save the data to their queues) and the near data will go to their queue waiting for the link L_{BN} to be activated. In the second time slot, the link L_{RF} and L_{BN} will be activated simultaneously. The BS sends the near data that are waiting in the queue to the MSs while it receives more far and near data from the wired network. The far user goes to the queue and near users will be sent to the MSs. Simultaneously, the RSs send the data in their queues to the far MSs.

Moreover, based on (Oyman, 2010) the links between BSs and MSs are assumed to be under frequency-flat multiplicative fading i.i.d. across users with complex channel gains $\{h_{F,u}\}$ U_u = 1 for U Far users and $\{h_{N,v}\}$ Vv = 1 for V Near users 1, where hF, uEℂ and hN, vEℂ are complex-valued random variables drawn from an arbitrary continuous distribution Fh with E(|hF, u|2) = E(|hN, v|2) = 1, ∀u, v (Oyman, 2010).

The links between RSs and MSs are assumed to be under frequency-flat multiplicative fading i.i.d. across users with complex channel gains {gF, u} Uu = 1 for U Far users and {gN, v} Vv = 1 for V near users, where gF, uE and gN, vEℂ are complex-valued random variables drawn from an arbitrary continuous distribution Fg with E(|gF, u|2) = E(|gN, v|2) = 1, ∀u, v (Oyman, 2010).

Resource allocation model: Among the different existing air interfaces, this study adopts the OFDMA as the resource allocation policy. In the OFDMA, the available time and frequency resources are orthogonally allocated across over each wireless link users to avoid inter-user interference and impairments due to multipath fading (Oyman, 2010). Multiuser scheduling has happened over K available OFDMA subchannels which are indexed by k = 1,..., K, RS and BS are deciding the downlink resource allocation base on the feedback of SINR which is approximated by

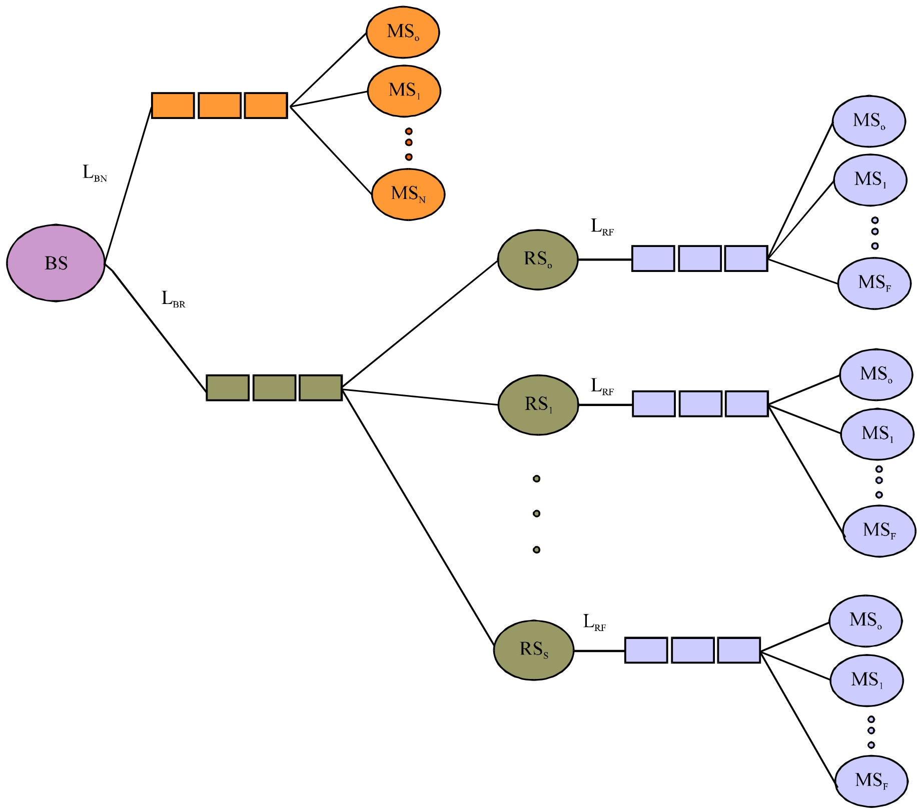

Fig. 4: RBCN queuing model

the MSs and are based on the Max-SINR opportunistic scheduling algorithm (Oyman, 2010; Tse and Viswanath, 2005) which always serves the best user with the highest instantaneous rate at any given time/frequency resource.

Channel gain: Channel gain is the gain that the signal transmitted by BS has when reaching MS at special time. This gain is due to the path loss (this loss increases over distance), shadowing, antenna gains and multipath fading. The channel gain is calculated based on the Eq. 1 (Oyman and Sandhu, 2007):

$$H_n(e^{j2\pi\theta}) = \sum_{l=0}^{L-1}\sqrt{\left(\frac{\varepsilon_n}{d_n^p}\right)}\, h_{n,l}\, e^{-j2\pi l\theta}\quad 0 \le \theta < 1 \tag{1}$$

where, L-1 is the assumption of the discrete-time channel represent the l-th tap (l = 0,... L-1) of the frequency selective fading channel. where, ε_n is the shadow fading over hop n, d_n is the distance between stations and p is the path loss exponent.

We consider Line-Of-Sight (LOS) BS to RS links as p = 2 for signal links and p = 3 for interference links. Non-LOS channels for the links from BSs and RSs to the MSs based on Erceg-Freenstein (EG) pass loss model (Anonymous, 2003).

SINR: The SINR is the signal to interference plus noise which is used to measure the quality of wireless links. Typically, the signals are fading with distance. The wireless networks are affected by background noise interfering strength of other simultaneous transmission that SINR attempts to represent them.

The Eq. 1 and 2 calculated the link's SINR for the far 2 and near 3 users:

$$SINR_{F,u} = \frac{SNR_F^{(r)} |gF, u|^2}{SNR_F^{(b)} |hF, u|^2 + 1'} \quad (2)$$

$$SINR_{N,v} = \frac{SNR_N^{(b)} |hN, v|^2}{SNR_N^{(r)} |gN, v|^2 + 1'} \quad (3)$$

where, the average received SNR for the LBF link equals $SNR_F^{(b)}$ and the average received SNR for the LBNlink equals $SNR_N^{(b)}$.

The average received SNR for the LRF link equals $SNR_F^{(r)}$ and the average received SNR between the each near user equals $SNR_N^{(r)}$.

The $g_{F,u}$ and $g_{N,v}$ represent the channel gain of the links between RSs and MSs while the $h_{F,u}$ and $h_{N,v}$ represent the channel gain of the links between BSs and MSs.

Representation model: The conceptual model of the system is subsequently converted to the computer simulation. As discussed in the SINR, there are two ways of achieving this, for which we use the GPL or simulation package. Due to the advantages of the GPL over simulation package such as the non-required for learning new programming languages or platform, flexibility, less execution time and the customization required for this study domain the simulation is developed using a general purpose C++ language.

DESIGN OF THE PROPOSED SIMULATOR

The proposed RBCN simulator developed and used to achieve all the performance evaluation experiments. The simulator is written in C++, evaluates the behavior of the Max-SINR opportunistic scheduling algorithm in a multi cell and multi user resulting from the network planning. The simulator comprises of traffic generation, the MS mobility and resource allocation. The interaction between radio network planning and RBCN simulator is shown in Fig. 5. The simulator takes the information of network model and the position of the MSs to build an actual model of the system. Due to the movement of the MSs in the network, our simulator is a dynamic simulator which can capture the real condition and offer result that is more accurate.

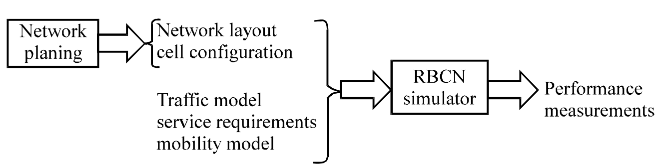

Fig. 5: Interaction between radio network planning and RBCN simulator (Perez-Romero *et al.*, 2005)

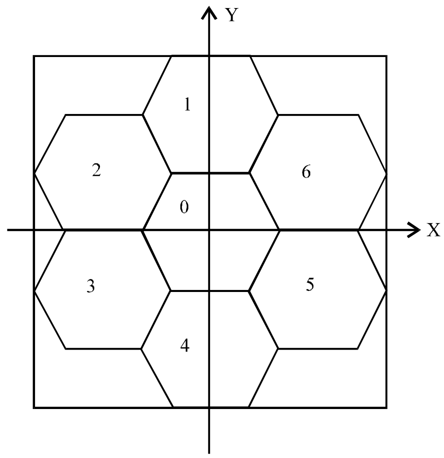

Fig. 6: Cell model

RBCN simulator structure: The main database of our simulator is the Cells and MSs Model, which these models relate to specific events. The cell model manages the arrival event of new call while the mobile manages the handoff and departure event. Separated from these events, bandwidth allocation events are existed that determine the way to allocate bandwidth or other resources to active MSs. These models and events are explained below in more details.

Cell model: There are seven equilateral hexagonal shape cells which are indexed by separated id and they are in the middle of the coordinate axes as shown in Fig. 6. The information about the position of the base stations, relay stations, near and far users and how cells are connected keeps in the global database cell model. This database used to find out which user is known as a Near user and which one known as a Far user; also, it is used to find the next cell for handoff of MSs. This part of the simulator is written with OpenGL and transferred to C++.

Mobile station model: The users (far and near) are randomly located in the system and the location of them are calculated by the BSs to find out which one is near and which one is far user. The MSs are indexed by a separated id. In each round, every 20 MSs will be added to the system. In Fig. 7 the flowchart for determining near and far user is shown.

Determining near and far users algorithm:

```
    To (all BSs calculate the distance of MS coordination from BSs coordination)
        {
    distanceBS = sqrt(((x(MSno)-BSx(BSno))×(x(MSno)-BSx(BSno)))+((y(MSno)-BSy(BSno))×(y(MSno)-BSy(BSno))))
        If (the distance BS <= 0.6)
            {
    Comment: Find out the nearest RS of that BS to the MS (for interference)
                For (all RSs of that BS)
    {
    distanceRS(RSno)=sqrt(((x(MSno)-RSx(BSno)(RSno))×(x(MSno)-RSx(BSno)(RSno)))+((y(MSno)-RSy(BSno)(RSno))×(y(MSno)-RSy(BSno)
    (Rsno))))
    If (distanceRS(RSno)<InfinitNO)
                    {
```

Algorithm: Continue

```
            InfinitNO = distance RS(RSno)
    }
    }
                MS is Near User, save BS and RS NO for this MS
    }
            Else if (the distanceBS <= 1.6 and distanceBS>0.6)
                {
    Comment: Making triangle from the MS with each cell edge (6 triangle),
                  For (all hexognal's points of that BS)
                     {
    distance a= sqrt (((Px(BSno)(pointno)-x(MSno))×(Px(BSno)(pointno)-x(MSno)))+((Py(BSno)(pointno)-y(MSno))×(Py(BSno)(pointno)-
    y(MSno))))
                      b = 1.6
            If (pointno = 5)
                      {
                       c = sqrt (((Px(BSno)(0)-x(MSno))×(Px(BSno)(0)-x(MSno)))+((Py(BSno)(0)-y(MSno))×(Py(BSno)(0)-y(MSno))))
    }
    Else
    {
                              c = sqrt (((Px(BSno)(pointno+1)-x(MSno))×(Px(BSno)(pointno+1)-x(MSno)))+ ((Py(BSno)(pointno+1)-y(MSno))
                                 (Py(BSno)(pointno+1)-y(MSno))));
    Calculate the space and area of each triangle
     S = 0.5×(a+b+c),
          area =  sqrt (S×(S-a)×(S-b)×(S-c)),
        Calculate the height of each triangle
      MH(pointno) = area/(0.8),
      }
      Calculate the sum of all heights
       sum = MH(0)+MH(1)+MH(2)+MH(3)+MH(4)+MH(5),
                                      If (the sum <= 8.34)
                                      {
                                      Comment: Find out the nearest RS of that BS to the MS (for interference)
                                        For (all RSs of that BS)
    {
    distanceRS(RSno)=sqrt(((x(MSno)-RSx(BSno)(RSno))×(x(MSno)-RSx(BSno)(RSno)))+((y(MSno)-RSy(BSno)(RSno))×(y(MSno)-RSy(BSno)
    (Rsno))));
    If (distanceRS(RSno)<InfinitNO)
                                          {
                                          Infinit NO = distance RS(RSno)
    }
    }
                                      MS is Far User, save BS and RS NO for this MS
    }
                                  Else
                                      {
                                      The MS is outside the coverage area
     }
    }
```

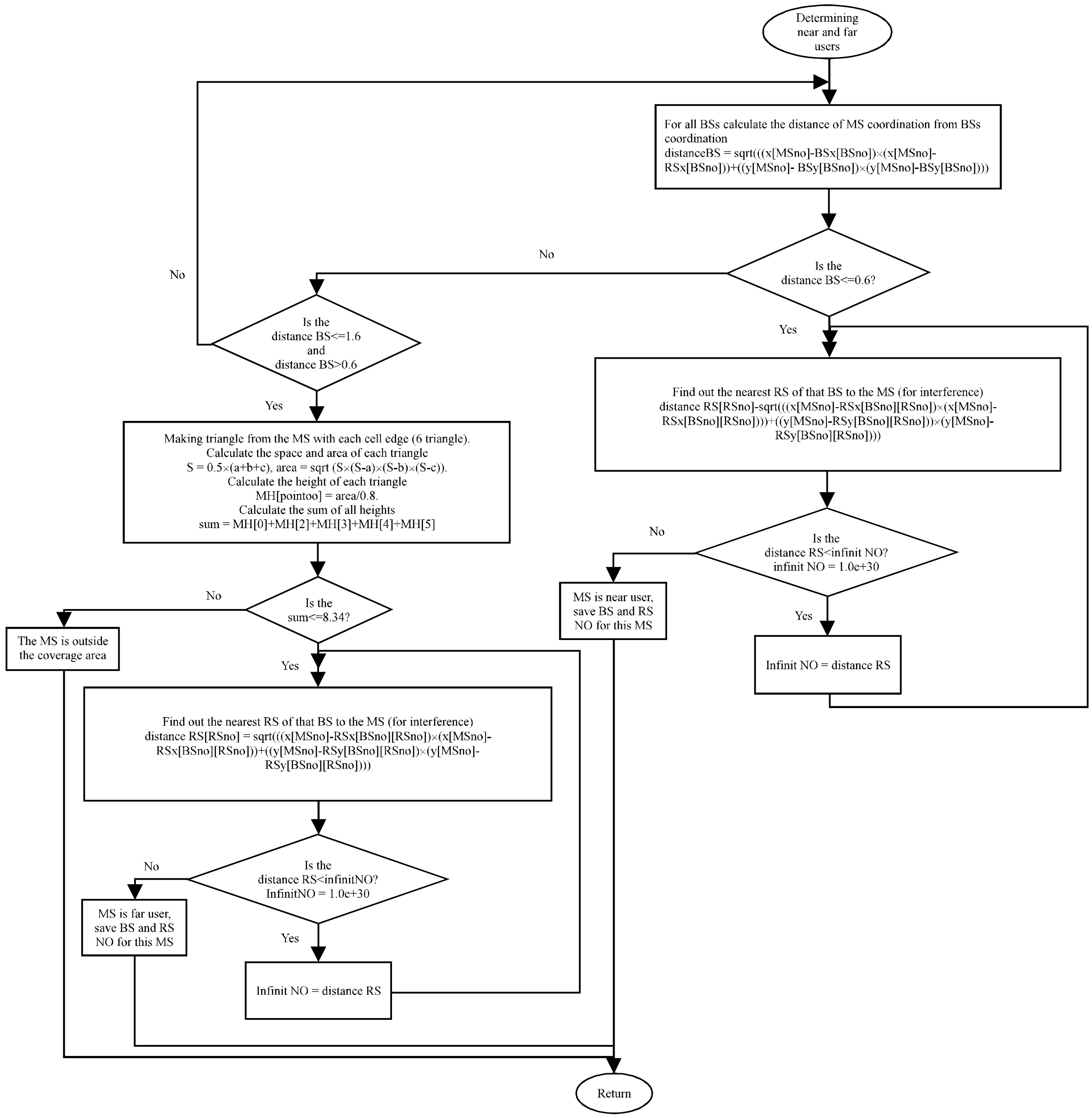

Fig. 7: Determining near and far user flowchart

Simulator events: An event is defined as an instantaneous occurrence that may change the state of the system which should process in order. The essence of RBCN discrete simulator is to define the events and their particular correlation. Our main events are arrival and departure which explained as follows.

Arrival event: Though, we are working on a downlink which is the transmission from BSs to the RSs or MSs, the arrival event is related to generate the time to determine when the BSs try to send data to the RSs or MSs. After the data come to the BSs, next data will be scheduled. First, the BSs check which data is this, for far or near user and then check which link is activated.

If the data is for far users and L_{BR} is activated, the BSs send the data to RSs and schedule the departure event. If all RSs are busy with processing the data, the BSs keep their data in the queue for next time to send. If the L_{BR} is deactivating and L_{RF} is active, the RSs find the best user to send the data and schedule the departure event for them. If both L_{BR} and L_{RF} are deactive, the users sending the channel quality feedback to the BS/RS, so the event will be return.

If the data is for near users and L_{BN} is active the BSs find the best users and schedule the departure event for that user, otherwise the data will be kept in the queue.

Figure 8 illustrates the flow chart of our arrival event. The pink color rectangles in the figure are working simultaneously.

Departure event: Departure event is the time that the RSs or the MSs received the data from the BS which they are connected. When the data send to the RSs or MSs, the departure event will be scheduled for them. This event also happened in the same time slots as explained in arrival event. First, the activation of the links will be checked. If L_{BR} is active, the RS will be departure and the data will be stored in their queue to wait for sending to the far users. On the other hand, the BS/RS queue (i.e., BR queue) will check if any data have inside or not, if yes the RS will be scheduled for the next departure event, otherwise the RS status will be idle.

If the LBR is deactivate and LBN and LRF are active the departure for far and near user will happen simultaneously. The BS/near (i.e., BN queue) and RS/far (i.e., RF queue) will be checked, if there is data inside or not. If yes, the MSs will be scheduled for the next departure, otherwise, the MSs status will be idle.

Figure 9 illustrates the flow chart of our departure event. The pink color rectangle in the figure is working simultaneously.

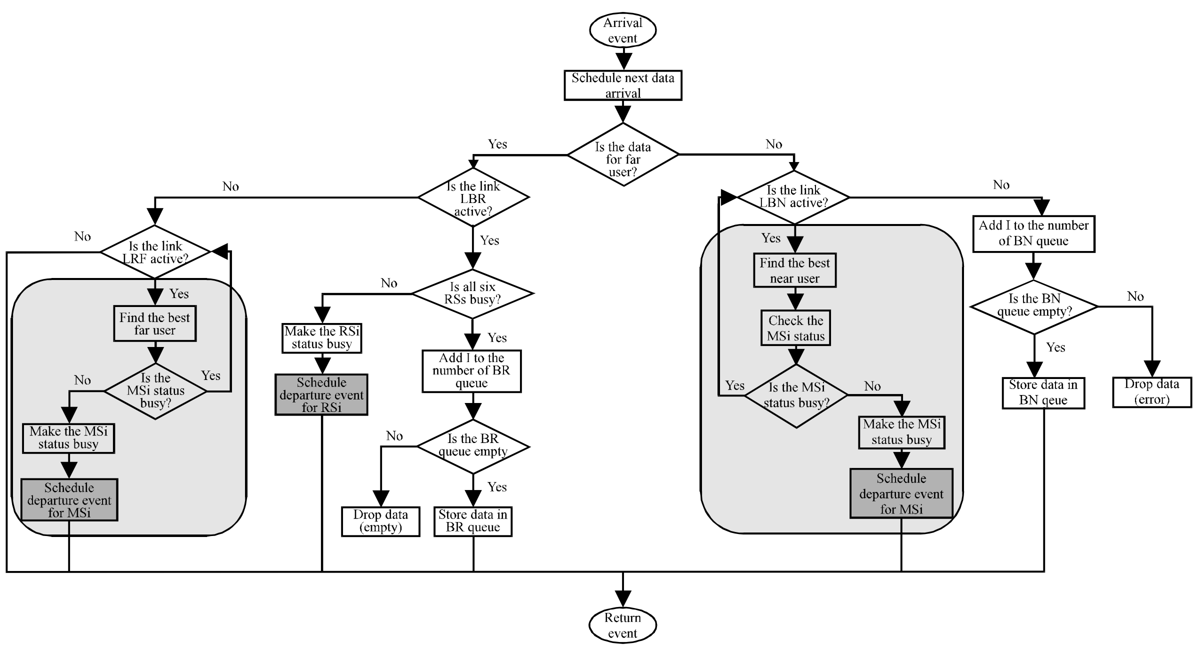

Fig. 8: Flowchart for an arrival event, queuing model

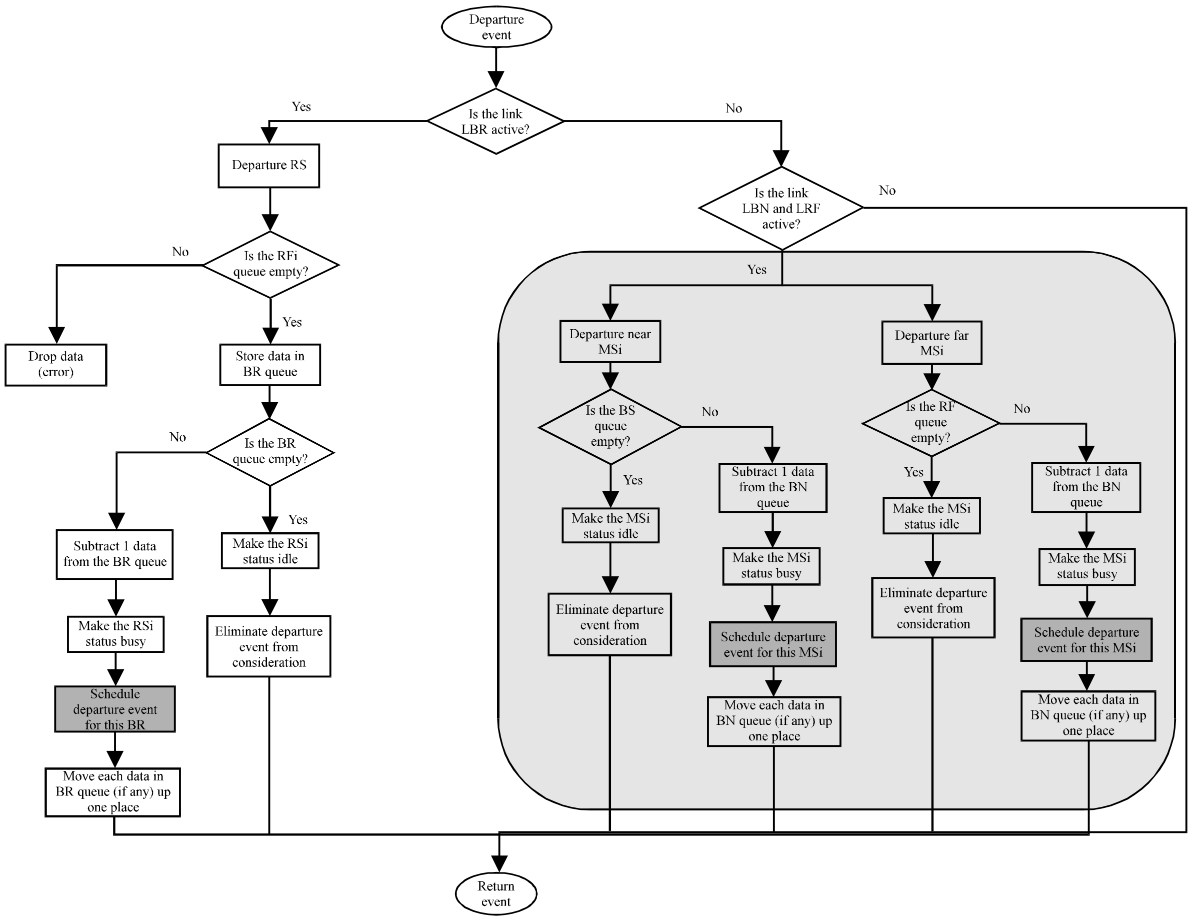

Fig. 9: Flowchart for departure event, queuing model

Performance metrics: Spectral efficiency is the performance metric which we evaluated in this simulation based on the formula below:

$$C^s(t) = \frac{1}{K}\sum_{k=1}^{K} \beta_{NF}(SINR_{N,v_k}(t,k)) + \min\left(\beta_B C\left(SINR_B(t,k), \beta_{NF}\frac{M}{m}C\left(SINR_{F,U_k}(t,k)\right)\right)\right) \quad (4)$$

where, K is the number of OFDMA subchannels, $C(x) = \log_2(1+x)$ and M is the number of RSs participated in each round.

Case study: A downlink operation in the RBCN in which the BSs receives the data and base on the data id wants to send it to the far or near uses is studied as a case study.

If the data is for far users when the L_{BR} links are active, the BSs send the data to the related RSs and the RSs keep the data to their queue. The time the L_{BR} is deactivated, the BS retains the data to the queue waiting for the link to be activated again. When the L_{BR} links are deactivated, the L_{RF} links are activated and the data will be sent to the far user base on the Max-SINR scheduling algorithms.

If the data is for near users and the L_{BN} link is deactivated the data keep in the related queue waiting for the L_{BN} to activate. The time L_{BN} is activated again the data will be scheduled to the MSs base on the Max-SINR scheduling algorithms.

SIMULATION VALIDATION

In our system, a 7-cell considered as in Fig. 2 (a main cell with the six-surrounded interfering cell). The first calculated radius which is fixed across all cells is D = 1. 6 KM, R = 1. 2 KM and with 600 m as a maximum range of the near users. i.e., D_n = 600 m. The time coefficients are ??$_{??}$ = 0.25, $_{NF}$ = 0.75. In Table 2, the simulation parameter is presented. We stated our downlink transmission protocol assumptions previous while considering simultaneous transmissions by the BS and RSs with varying degrees of reuse (of time and frequency resources) and characterized their spectral efficiency performance in the multi-cellular OFDMA setting under the presence of opportunistic scheduling policies. We evaluate our simulator with the (Oyman, 2010) Max_SINR algorithm. However, we change the simulation and write our own code, we get almost the same results.

In Fig. 10, we compare our simultaneous Max_SINR algorithm with the simultaneous Max_SINR algorithm in (Oyman, 2010). The scarce difference in our result is because they used monte carol simulation. These results are gained by averaging the expressions in Eq. 3 over a large number of randomly generated fading realizations. The increase in average spectral efficiency with

Table 2: Relay-based multi cellular network link budget for BS_MS, BS_RS and RS_MS Channels

Parameter	BS_MS channel	BS_RS channel	RS_MS channel
Transmit power (RMS) (dBm)	36	36	29
Transmitter gain (dBi)	6	6	6
Noise PSD (dBm Hz^{-1})	-167	-167	-167
Bandwidth (MHz)	20	20	20
Path loss model	EG	LOS or near LOS	EG
Shadowing std (dB)	8	4	8
Tx antenna height (m)	25	25	12
Rx antenna height (m)	2	12	2
Carrier frequency (GHz)	3.5	3.5	3.5

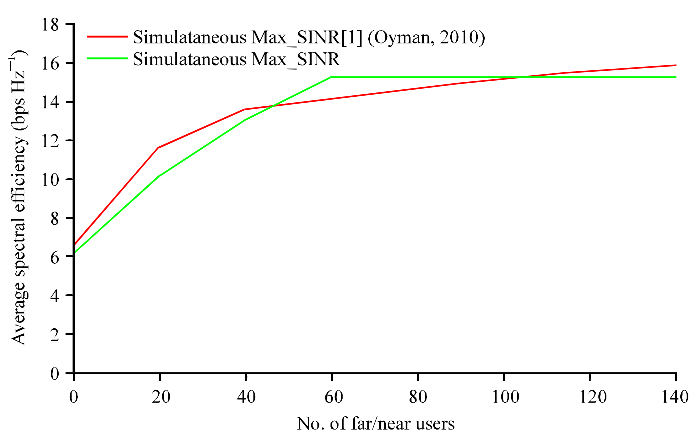

Fig. 10: Spectral efficiency comparison

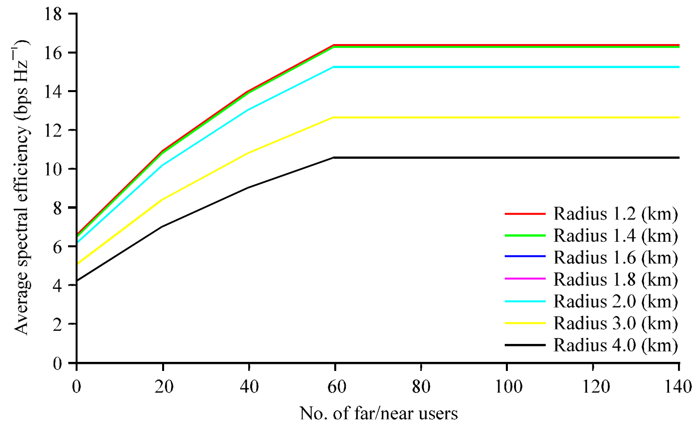

Fig. 11: Spectral efficiency comparison between different numbers of users based on the cell radius

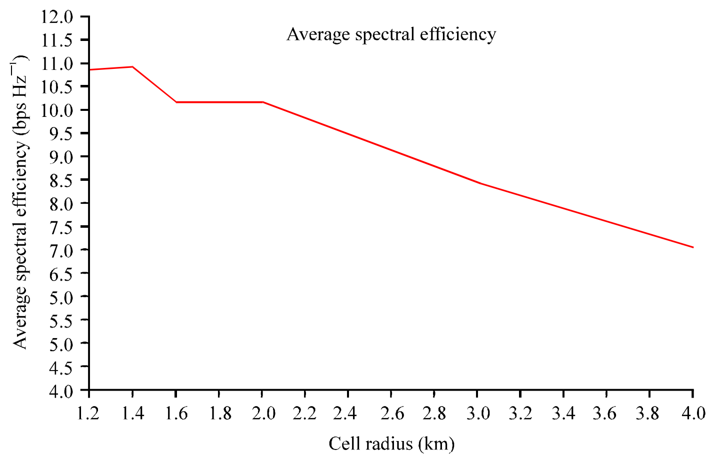

Fig. 12: Spectral efficiency comparison base on cell radius when number of user = 20 μsec and when number of user = 20

increasing number of users can be attributed to multiuser diversity realized by opportunistic scheduling of far/near users in a channel-dependent manner exploiting the time and frequency selectivity of the wireless links as well as the independence of channel variations among the far/near users.

In Fig. 11 and 12, the spectral efficiency compare based on the different cell radius which as we can see for a small D (upto about 2 km) spectral efficiency is almost independent of the cell radius (interference limited), whereas for larger D, spectral efficiency decreases rapidly with D (noise limited).

CONCLUSION

We developed opportunistic scheduling for RBCN in downlink mode base on queuing theory by using discrete event simulation which is more suitable for RBCN as the system evolves over time. For the developer to understand both logic and how this is translated to discrete event simulation, we use queuing theory.

The spectral efficiency performance is analyzed based on a system-level capacity analysis and simulation validation framework using multi-cellular system models in the presence of co-channel interference, frequency-selective fading and OFDMA modulation. The presented RBNC simulator is able to capture the results of both numerical and simulation of the previous study. The uniqueness of the developed simulation is, it can be extended for new procedures take into the system and provide a low complexity. A key learning from our study is that significant spectral efficiency gains can be achieved through spectrum reuse by the BS and RSs in the same cell (and sector) which depend to the radius of the cells.

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