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THROUGHPUT UTILITY ENHANCEMENT OF COGNITIVE WIMAX WITH FEMTO-CELLS

[1]A. KARTHIKEYAN, [2]ARUNKUMAR. K, [3]V.SRIVIDHYA, [4] T.SHANKAR
[1]Assistant Professor., SENSE, VIT University, Vellore
[2]M.Tech Communication Engineering Student, SENSE, VIT University, Vellore
[3]Assistant Professor, Kingston Engineering College Anna University Chennai,.
[4]Assistant Professor (Sr)., SENSE, VIT University, Vellore

Email: [1]akarthikeyan@vit.ac.in, [3]srividhya@kingston.ac.in, [4]tshankar@vit.ac.in

ABSTRACT

WiMAX with femto-cells is a cost effective and spectrally efficient next generation broadband wireless communication systems. Femtocells are perceived as having a strong potential to provide high data-rate services with increased coverage at low cost. Femtocells will allow new services and business models to be offered to indoor users. Almost parallely, the WiMAX standard has emerged as a potential candidate technology for the future wireless networks. WiMAX femtocells are currently under development and will therefore play an important role in the world of indoor broadband wireless access. However, several aspects of this new technology, such as the access method and interference avoidance techniques play a crucial role in the amount of interference caused to co-channel deployed macrocells. Cognitive radio is a recent technology which enhances spectrum efficiency by dynamic spectrum sensing. So by the integration of WiMAX with femto-cells and cognitive radio further enhances the spectrum efficiency. The integration faces certain challenges in terms of frequency reuse, power control, interference, complexity etc. So it is required to find the optimum power that is to be transmitted from the base station and also the optimum routes with optimum channel allocation, so that the interference is reduced and frequency reuse is possible. Also by implementing multi-hop cooperative communication, complexity of the problem further increases. The constraints are mathematically modeled using stochastic network model. Three resource allocation policies are introduced and it is proved using Lyapunov theory that these policies leads to the throughput enhancement. It is showed that how relaying and co-operative relaying affect the throughput. At-last an algorithm is presented for resource allocation satisfying the objectives of the policies.

Keywords: *Macro-Base Station (MBS), Femto-Base Station (FBS), Lyaunov Function, Multi-Hop Cooperative Communication, Hungarian Algorithm, Maximum Bipartite Matching*

1. INTRODUCTION

Wireless communications are nowadays one of the most skyrocketing sectors in the communications market and research areas. It is already in the past when the number of wireless terminals clearly exceeded the number of fixed terminals for the first time and, in recent years, operators have been experiencing a steady increasing demand for higher data rates and better quality of service. The advent of 3G wireless networks and its successful introduction in multiple markets all over the world also started the emergence of new and diverse mobile services that generated a great increase in capacity demands. Video streaming and Internet browsing, along with the increase of popularity of the Web 2.0, are currently the main sources for this bandwidth increase requirement. Operators cannot depend or rely on voice services for revenue anymore.

IEEE 802.16 WiMAX are possible future technologies for WAN. It provides voice, data, and multimedia services at low cost on an all IP (packets)
network. Femto-cells are Femto-cell base stations (BS) which are low-power, short-range, low-cost indoor cellular base station for better coverage and capacity. They are much smaller than the standard Macro-cell cellular towers. They are also called home base stations. [10]

Femto-cells are similar to Wi-Fi major difference comes in that Wi-Fi uses un-licensed spectrum, femto-cells uses licensed spectrum like GSM, 3g, WiMAX, LTE etc. into which it is fed. Cognitive radio (CR) is the technology using which un-used channels are sensed and assigned to the secondary users. So by using these three technologies together we can exploit the so called spectrum holes. But along with this there-comes a large number of constraints.

However, traditional WiMAX architectures and MAC-layer protocols are hobbled by the holdover from cellular networks: they lack dynamic utilization of spectrum holes and are essentially based on single-hop transmissions, requiring globally available channel resources.

The existing state-of-the-art resource management protocols have to carefully coordinate the transmissions of macro and femto cells in a time-sharing mode, which has inherent weakness on overlooking the special network characteristics and hence missing the bulk of channel reuse opportunities.

Fig.1 shows a WiMAX scenario with 6 femto-cells. [2] The users which come under femto-cells are primary users (PU) and those users which are mobile are secondary users (SU). The primary users enjoy dedicated channels good signal quality etc. The SU’s will be fed from the macro BS. They use the channels which are presently un-used by the PU’s or the channels which won’t cause interference to the primary user transmission. SU’s communicate directly with macro-BS. The edge SU’s will be fed using relay routes. The users themselves act as relays. Thus extend the coverage area of the macro-BS. Since the TX range of femto-cell is small it allows abundant frequency reuse opportunities.

In WiMAX, femtocells are a cost-effective means of providing ubiquitous connectivity. Users that reside in femto cells experience increased throughput due to the shorter ranges [2]. Fig. 1 shows a typical WiMAX network consisting of one macro base station (BS) and six femtocells, serving two classes of users: primary user (PU) and secondary user (SU). PUs communicates with the corresponding femto BSs with dedicated channels, enjoying guaranteed quality of services (QoS). SUs are highly dynamic and communicate directly with macro BS with best effort services.

As the power used by femto BSs is an order of magnitude less than macro BS, the serving area of each femtocell is quite limited (shown by shadow circle areas). The smaller size of femtocells creates abundant opportunities for spatial reuse: the transmissions outside the femtocells are able to be executed over the same channels used inside femtocells. Thus, they work in a completely distributed fashion, and the channel availability in the network is location-dependent and dynamic for SUs due to the bursty channel use by PUs and SU mobility.

One of the disadvantages of this is that the signaling overhead increases considerably. Large amount of resources are used for signaling because of relaying, power control, channel sensing etc. But the advantages of these techniques over-ride this problem. There are papers which deal with reducing the overhead in which one technique is traffic aggregation. Fig. 2 shows how a femto-macro scenario works. Femto-cell may support around 5-6 users when number of users increases throughput of individual user reduces. They allow different types of access like open access, closed access and hybrid access. Hybrid means it is adaptive between open and closed. This has been discussed in some other papers.

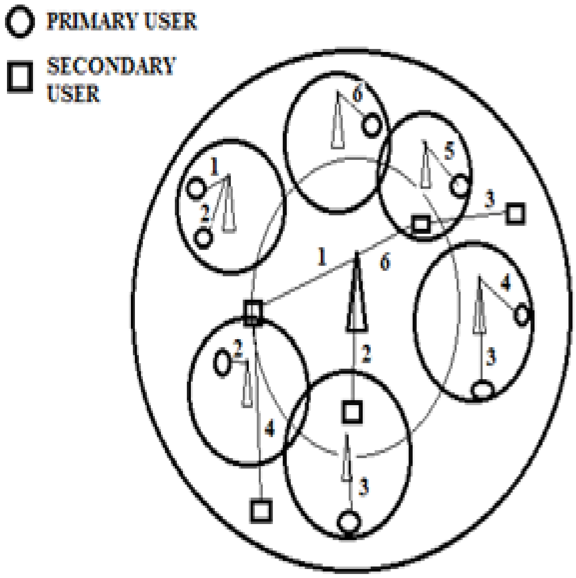


Fig. 1. An example of cognitive WiMAX with femto-cells

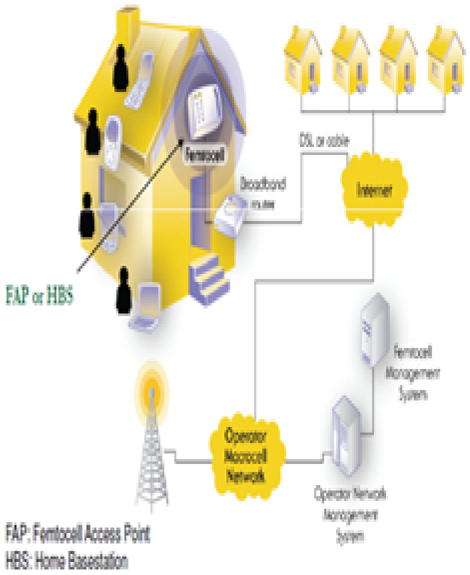


Fig. 2. Femto macro scenario

Some of the challenges faced by wimax with femto cells are:-

- The access method
- Physical cell identity
- Neighboring cell list
- Mobility management
- Interference analysis
- Time synchronization

2. SCENARIO DESCRIPTION

In Fig. 1 there is 1 macro-BS and 6 femto-BS. Here channels 1, 2, 3, 4, 5, 6 are dedicated channels for the PU's. The transmission from macro-BS will be such that the channel allocation won't create interference to the PU's. In the fig channel 1 is assigned for a SU because it doesn't come in the interference range of the macro transmission. Similarly while relaying also all these have to be considered. We cannot transmit and receive in the same channel simultaneously during relaying. Because the signal which is being received will be a weak signal and transmitted signal will be strong signal. So when they are done in the same channel the weak signal will be suppressed by the strong signal. Thus the resources have to be allocated dynamically. The Fig. 3 is a MATLAB simulation of such a scenario. Here macro BS is shown to have a 1km radius and there are a no of SU's shown in red colour and the circle with a cross represents house with femto-cells. Within a range of 20m any user comes it is checked in the femto-BS that whether he is a registered user. If he is a registered user then he will be handoff to the femto-BS. They are represented by blue colour. Others are the ones which are fed by the macro BS. Here we used certain probability values for a house having femto-BS, a user to be PU. Also, certain probability was given for two femto-cells to be non-overlapping.

3. SYSTEM MODELLING

3.1. Modeling of Cognitive Wimax With Femto-Cells

In this scenario both the macro-BS and the SU's are fitted out with cognitive radios for channel sensing, power control etc. scenario consists of 1 macro-BS F femto-cells with A PU's and N SU's. C orthogonal channels are used here using OFDMA technique. Femto-cells are home BS and have dedicated PU's which have pre-allocated channels to support guaranteed QOS. But for SU's resource allocations is purely dynamic and are served opportunistically after channel sensing.

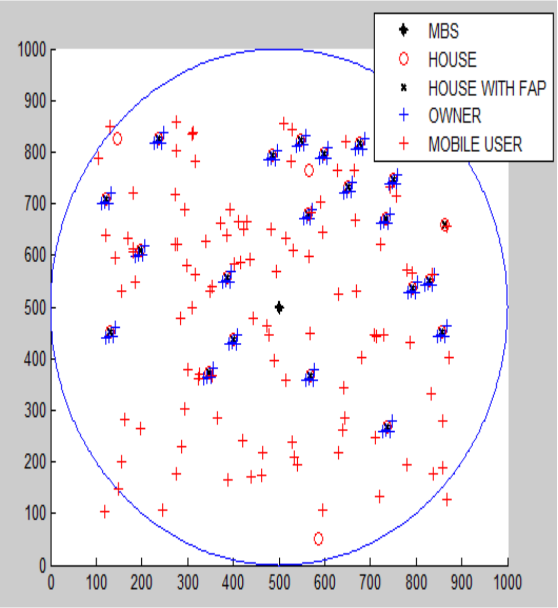


Fig. 3. Femto-Macro deployment

Let us define some terms which are used for formulating the constraints. Let S(t) = $\{S_a^c(t)\}_{AxC}$ represent the channel states on a particular time slot. $S_a^c(t) = 0$, means channel c is occupied by PU a. Otherwise $S_a^c(t) = 1$. This Channel accessibility information is represented by H(t) = $\{h_n^c(t)\}_{NxC}$, $h_n^c(t) = 1$ if SU n can access channel c. Dynamicity of the macro-BS and SU's are satisfied using CR's. $P_{BS}(t) = \{P_{BS}^c(t)\}_C$, represent the macro BS transmission power on each channel. $U_{BS}(t) = \{\mu_n^c(t)\}_{NxC}$, represents the channel allocation to the SU's in the macro-cell and $\mu_n^c(t)$ is a binary variable which captures the assignment of the channel c. $P_{SU}(t) = \{P_n^c(t)\}_{NxC}$ is the SU power allocation and $U_{SU}(t) = \{\mu_{mn}^c(t)\}_{N\,NxC}$ represents the channel allocation to the SU's co-operative transmission.

3.2. Mathematical Modeling of the Constraints

The power and spectrum resources can be controlled such that the spectrum can be fully utilized and efficient frequency reuse can be done. According to our scenario we have 4 kinds of constraints. Considering these constraints three resource allocation policies are developed. So it is necessary to understand these constraints.

3.2.1. Power constraints

$$\sum_{c=1}^{C} \boldsymbol{P_{BS}^c(t)} \le P^{max} \qquad (1)$$

$$\sum_{c=1}^{C} P_n^c(t) \le P_n^{max} \qquad (2)$$

$$P_{BS}^C(t).\, g_a^c(t).\, S_a^c(t) \le \beta \qquad (3)$$

First and second inequality shows that there is a restriction on the max transmission power for both macro-BS and SU's. Third inequality shows that the power received at the PU on the same channel which is being used by it should be less than a tolerable value β. $g_a^c(t)$ Is the propagation gain from the macro-BS to the PU a at channel c. For transmission from node i to j propagation gain is defined as: $g_{ij} = {d_{ij}}^{-n}$ (4) d_{ij} is the distance

3.2.2. Channel constraints

$0 \le \sum_{n=1}^{N} \mu_n^c\,($

$$\mu_{mn}^c(t) \le h_m^c(t), \quad \mu_{mn}^c \le h_n^c(t) \qquad (6)$$

The eqn (5) shows that macro-BS cannot use same channel to transmit to multiple SU's. For transmitting from node m to n both m and n should have the channel c status as free. Another constraint is that the multi-cast power received by a SU if it exceeds a particular threshold value then that channel is considered to be unavailable i.e.

$$\mu_{mn}^c(t) \le l_m^c(t), \quad \mu_{mn}^c \le l_n^c(t) \qquad (7)$$

$$l_n^c(t) = \begin{cases} 1 & if\ P_{BS}^C(t).\, g_a^c(t) \le \gamma \\ 0 & otherwise \end{cases} \qquad (8)$$

3.2.3. Cooperative constraints

$$0 \le \sum_{m=1}^{N} \mu_{mn}^c\,(t) \le 1 \qquad (9)$$

$$0 \le \mu_n^c(t) + \sum_{m=1}^{N} \mu_{mn}^c\,(t) \le 1 \qquad (10)$$

$$0 \le \sum_{m=1}^{N} \mu_{mn}^c\,(t) + \sum_{m'}^{N} \mu_{nm'}^c\,(t) \le 1 \qquad (11)$$

Inequality (9) shows that a SU cannot be served by multiple SU's via the same channel. Means nodes receive from different SU's through different channels. Inequality (10) shows that transmission and reception cannot be done through the same channel. This is because the receiving signal will be a weak signal and the signal to be transmitted will be a strong signal which may suppress the receiving signal i.e. in the same channel [7].

3.2.4. Flow constraints

$$U_n(t) = \sum_{c=1}^{C} \mu_n^c(t) f_n^c[n](t) + \sum_{c=1}^{C} \sum_{m=1}^{N} \mu_{mn}^c(t) f_{mn}^c(t) \qquad (12)$$

$$f_{nm}^c(t) \leq \omega_{nm}^c(t) \qquad (13)$$

$$\sum_{c=1}^{C} \mu_{nm}^c(t) f_{nm}^c(t) = \sum_{c=1}^{C} \mu_n^c(t) f_n^c[m](t) \qquad (14)$$

$$\sum_{m=1}^{N} f_n^c[m](t) \leq \mu_n^c(t) \omega_n^c(t) \qquad (15)$$

$$U_n(t) = U_1, U_2, \dots \dots \dots, U_n$$

is the throughput vector on each SU. Since the transmission range of the node is less we go for relaying or multi-hop technique. By this we get better load balancing and also flexibility. We also go for cooperative transmission which uses multi-path propagation to effect. $f_n^c[m](t)$ is defined as the flow rate of the transmission from macro-BS to the SU n over the channel c and the data will be destined for m. The throughput on each secondary user is given by eqn (12). Eqn (13) shows that the flow rate cannot exceed the link capacity. The flow rate of the transmission from node n to node m for the data destined for m should be equal to the flow rate of the transmission from macro-BS to the intermediate node n with the data destined for node m. Eqn (15) shows that the total flow rate shouldn't exceed the total capacity.

$$\omega_n^c(t) = B.log_2\left(1 + \frac{P_{BS}^c(t) g_n^c(t)}{N_0}\right) \qquad (16)$$

$$\omega_{nm}^c(t) = B.log_2\left(1 + \frac{P_n^c(t) g_{nm}^c(t)}{N_0}\right) \qquad (17)$$

Eqn (16) & (17) are the capacities of transmission from macro-BS to SU n and also cooperative transmission from SU n to SU m. capacity is limited because we have constraint on power that can be transmitted.

Keeping all these objectives in mind we have to maximize the throughput. So if we implement three policies in terms of power control, flow routing and also cooperative transmission. By power control frequency reuse becomes much easier and scheduling feasibility is also obtained. Cooperative transmission enhances the coverage area of the BS. Also the cell edge users will get better signal quality. It also exploits multipath propagation in an efficient way. Flow routing is something important because when we use cooperative transmission the proper relays have to be found out. It should not result in loss of packet or overflow. Relay selection is an important one. With these constraints and objective of maximization of throughput with proper fairness we can go for greedy optimization, it will be easy when we know the achievable throughput region for SU's. But this part actually remains unknown. To address this problem we formulate a resource management protocol.

4. RESOURCE ALLOCATION POLICIES AND LYAPUNOV OPTIMIZATION

When the objective of the problem is maximization or minimization subject to stability we use Lyapunov optimization which is based on stability of queues. Lyapunov function L(t) is defined as a measure of network congestion [1]. When L(t) is small queue backlog is small and when L(t) is large the queue backlog is large. We use a stochastic network model for developing the resource management policies. It is based on the queue backlogs of the SU's. Macro-BS maintains a data buffer (queue) for each SU. $B_n(t)$, denotes the queue backlog. For each time slot packets arrive at the queue at a rate $R_n(t)$the queue backlog should be bounded and stable. So $R_n(t)$ should be properly tuned. Based on the stochastic network model queuing dynamics can be written as: -

$$B_n(t+1) = max\{B_n(t) - U_n(t), 0\} + R_n(t) \qquad (18)$$

$$r_n = \lim_{t\to\infty} \frac{1}{t} \sum_{\tau=0}^{t-1} R_n(\tau) \qquad (19)$$

Let $r_n$denote the average arrival rate on all the SU's. Since we go for cooperative transmission there may be errors due to channel sensing errors. That means it creates interference to the PU, it will be

counted as a collision of the PU. To find the no of collisions we use the term$E_a^c(t)$: -

$$E_a^c(t) = \sum_{m=1}^{N} \sum_{n=1}^{N} \mu_{mn}^c(t) I_m^a(t)(1 - S_a^c(t)) \qquad (20)$$

The interference by the SU m on PU a is shown by the term $I_m^a(t)$.

$$e_n^c = \lim_{t\to\infty} \frac{1}{t} \sum_{\tau=0}^{t-1} E_a^c(\tau) \qquad (21)$$

The SU's will be aware of an interference buffer at the PU. And the interference information will be tracked. Actual aim is to maximize the aggregate throughput of SU's under the fairness criteria and by satisfying all the above constraints.

$$\max \quad \sum_{n=1}^{N} \theta_n r_n \qquad (22)$$

Sub to (1) – (21)

4.1. Resource Management Policies

The policies were designed to satisfy the problem in eqn (22) and are based on stochastic network optimization. The three policies are: -

4.1.1. Flow control

At each time slot, macro-BS controls the data rate admitted to the data buffer of each SU.

$$\min \quad R_n(t)(B_n(t) - V\theta_n) \qquad (23)$$
$$\text{Sub to} \quad 0 \le R_n(t) \le R_{max}$$

The solution to this is a threshold based solution. The parameter V is a constant, according to the system requirement it can be tuned. The solution is given by

$$R_n(t) = \begin{cases} 0 & if\ B_n(t) > V\theta_n \\ R_{max} & otherwise \end{cases}$$

The solution clearly shows that if we have a large backlog means the macro-BS will reduce its transmission rate to avoid packet loss it can be even 0. When the backlog is less or nil then the arrival rate is increased it may be increased to R_{max}.

4.1.2. Macro allocation

At each time slot, the power and channel allocation decisions taken by the macro-BS are based on the macro allocation policy: -

$$\max \quad \sum_{n=1}^{N}\sum_{c=1}^{C} B_n(t)\omega_n^c(t)\mu_n^c(t) \qquad (24)$$

Sub to (1), (3), (4), (16)

For maximizing the above term the values of buffer or capacity should be high. $\mu_n^c(t)$, value will be either 1 or 0 which shows whether the channel c is available for transmission or not. So it is clear that a higher capacity link has higher chances of getting the channel also we should consider the SU with a higher backlog in the buffer. It is understood that the SU didn't get any allocation in the previous slot. So it will be given a priority this time. Thus it is kept stable and packet loss is avoided.

4.1.3. Cooperative allocation

At each time slot, the power and channel allocation decisions taken by the SU for cooperative transmission are based on the cooperative allocation policy: -

$$\max \sum_{a,m,n} \mu_{mn}^c(t)\{(B_n(t) - B_m(t))\omega_{mn}^c(t) - X_a^c(t)I_m^a(t)(1 - Y_n^c(t))\} \qquad (25)$$

Sub to (2), (5), (6), (7), (17)

The term $B_n(t) - B_m(t)$ shows that for maximizing we should require higher backlog for SU n means for the SU m to participate in cooperative transmission backlog of m should be less than SU n. Means n has a higher priority for getting the resources than m. Also interference caused to the PU should be very small so that the term is maximized.
Now we will prove using Lyapunov's theory that using these 3 policies we can reach the objective of eqn (22).

4.2. Performance Analysis

We illustrate the performance of the resource allocation policies using some upper and lower bounds. We prove that the queue will be bounded and stable.

4.2.1. Backlog performance

Let us consider that backlog of SU at time slot 0 is 0 i.e. $B_n(0) = 0$. Then the data buffer backlogs are bounded as:

$$B_n(t) \le B_{max} \cong V\theta_{max} + R_{max} \qquad (26)$$

Proof: $B_n(0) = 0 < B_{max}$ Suppose that $B_n(t) \le B_{max}$. For this to be true we have to prove it for $B_n(t+1)$. There are two cases, first $B_n(t) \le B_{max} - R_{max}$. From eqn (18) $B_n(t+1) \le max\{B_{max} - R_{max} - U_n(t), 0\} + R_{max}$, which show that $B_n(t+1) \le B_{max}$, second case $B_n(t) > B_{max} - R_{max}$, then $B_n(t) > V\theta_n + R_{max} - R_{max} = V\theta_n$, so when $B_n(t) > V\theta_n$by flow control policy we make $R_{max} = 0$ so that $B_n(t+1) \le B_n(t) \le B_{max}$. Thus the system will remain stable.

4.2.2. Utility performance

Here we will show the time avg throughput utility achieved by the protocol is within $\frac{\tilde{B}}{V}$ of the optimum value:

$$\lim_{t\to\infty} inf \frac{1}{t}\sum_{\tau=1}^{t-1}\sum_{n=1}^{N}\theta_n E\{R_n(\tau)\} \geq \sum_{n=1}^{N}\theta_n r_n^* - \frac{\tilde{B}}{V} \quad (27)$$

Where r_n^*, is the optimum throughput value and by proving eqn (27) we show that r_n^* is optimum. This is possible only if we use three of the resource allocation policies.

Let $Q(t) = \{Q_1, \dots \dots \dots, Q_k\}$ be a vector of queue backlogs. Let W(Q(t)) be a non-negative function. Where W(0) represents the network is empty, W(Q) is large means network is congested and W(Q) is small means the backlogs are less. The function can be any non-negative function here we use a quadratic lyapunov function. $W\big(Q(t)\big) = \sum Q_i^2(t)$. We define another term which is called lypunov drift $\Delta\big(Q(t)\big) = E\big\{W\big(Q(t+1)\big) - W\big(Q(t)\big)\big\}$. The drift value should be minimized so that the queues remain stable.

Theorem 1: Delayed lyapunov optimization

Suppose there exists finite constants V>0, B>0 and d>0 and E{W(Q(d))}<∞ for every time slot t<d. If lyapunov drift satisfies:

$$\nabla(t) - VE\{f(t)\} \leq B - Vf^* \quad (28)$$

Then, we have:

$$\lim_{t\to\infty} inf \frac{1}{t}\sum_{\tau=1}^{t-1} E\{f(\tau)\} \geq f^* - \frac{B}{V}$$

The set of Q(t) is a set which consist of backlogs of both PU and SU. So Q(t) is given by:

$\{B_1(t), \dots, B_n(t), X_1^1(t) \dots, X_1^C(t), X_A^1(t), \dots, X_A^C(t)\}$

f(t) is the aggregate throughput utility at each time slot. $f(t) = \sum_{n=1}^{N}\theta_n R_n(t)$ Optimum value of $R_n(t) = r_n^*$. The lyapunov function is defined as:

$$W\big(Q(t)\big) = \frac{1}{2}\sum_a\big(\sum_n\big(B_n^2(t)\big) + \sum_c\big(X_a^{c2}(t)\big)\big) \quad (29)$$

Lyapunov drift is determined using the relation: $\Delta\big(Q(t)\big) =\leq B - E\sum_{n=1}^{N} Q_n(t)$, using this we re-write the eqn as:

$$\Delta(t) \leq B - E\big\{\sum_a\sum_n\big\{B_n(t)\big(U_n(t) - R_n(t)\big)\big\}\big\} - E\{\sum_n\sum_c\{X_a^c(t)\big(\rho_a^c - E_a^c(t)\big)\}\} \quad (30)$$

Where B=$\frac{1}{2}(A.N.(B_{max})^2 + \sum_a\sum_c(\rho_a^c)^2 + A.C)$

Subtract $V.E\{\sum_{n=1}^{N}\theta_n R_n(t)\}$ from both sides of drift inequality. Substitute eqn's (11), (12), (13), (20) and rearranging the terms we will get as:

$$\Delta(t) - VE\{\sum_{n=1}^{N}\theta_n R_n(t)\} \leq B - \sum_{a=1}^{A}\sum_{c=1}^{C}\rho_a^c E\{X_a^c(t)\} + \mathrm{A}.E\big\{\sum_{n=1}^{N} R_n(t)(B_n(t) - V\theta_n)\big\} - \mathrm{A}.E\{\sum_{n=1}^{N}\sum_{c=1}^{C} B_n(t)\omega_n^c(t)\mu_n^c(t)\} - E\big\{\sum_{a,m,n,c}\mu_{mn}^c(t)\big\{\big(B_n(t) - B_m(t)\big)\omega_{mn}^c(t) - X_a^c(t)I_m^a(t)\big(1 - Y_a^c(t)\big)\big\}\big\} \quad (31)$$

Here our resource management policies are represented by the last three terms on the right side. The drift value should be minimized so that the queues are strongly stable. According to our policies the eqn (23) the objective is to minimize and the objective of eqn (24) and (25) is to maximize. To minimize drift value in eqn (31) the right side should be minimized. For that the 2nd term should be minimized and 3rd and 4th terms must be maximized. So eqn (31) is satisfied by the resource management policies. Now we show that the throughput utility $R_n(t)$we obtain will be optimum. We use a stationary randomized policy that selects an optimum allocation in every time slot.

$$E\{R_n^{SR}(t)\} = r_n^* \quad (32)$$

$$e_a^{c,SR} = \lim_{t\to\infty}\sum_{\tau=0}^{t-1} E\{E_a^{c,SR}(\tau)\} \leq \rho_a^c \quad (33)$$

These are the steady state values obtained from the SR policy. Using this we rearrange eqn (30) and conclude as :

$$\Delta(t) - V.E\{\sum_{n=1}^{N}\theta_n R_n(t)\} \leq \tilde{B} - V\sum_N \theta_n r_n^* \quad (34)$$

This is equivalent to our theorem 1. Thus it proves eqn (27). So the queues are strongly stable and the policies give r_n^* as the optimum throughput utility.

5. SOLUTION FOR THE MAXIMIZATION PROBLEMS

Both the eqns (24) & (25) can be solved in similar ways. The solution is found out in two steps. In the first step we will find out the hidden variable. Here it is the power allocation variable P_{BS}. This term is kept as variable and others will be fixed. This step is called the power allocation step. After this the eqn will look like a linear optimization problem which is quiet easy to solve. But the second step is the actual problem we are looking forward to. Here we will keep $U_{BS}(t)$ as the variable which takes either 0 or 1 value. Then P_{BS} is fixed. Here the whole problem can be thought of as a maximum bipartite graph problem. [6] A bipartite graph is constructed $A = (\emptyset X x, E)$. The graph consists of Su's as one set of vertices represented by $\emptyset$ and x represents the channels available for them. The allocation of channels should be done in such a way that it maximizes the total weight. The edges have a certain wait and it is given by

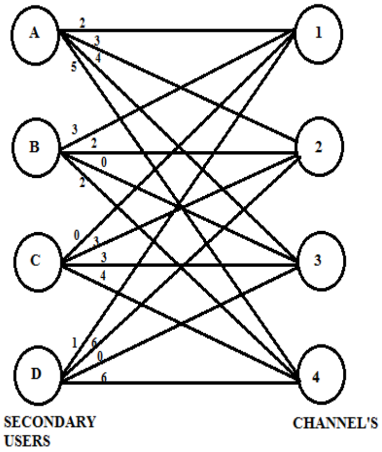
$$)\omega_n^c(t)$$

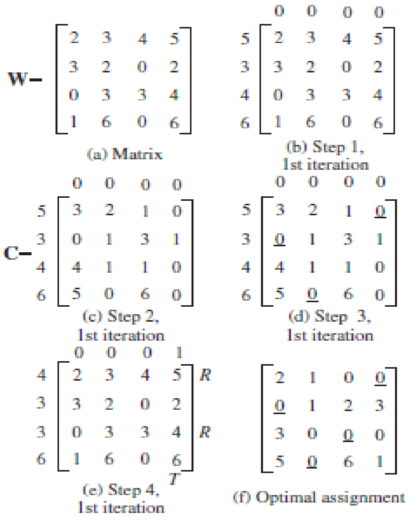
The algorithm which we use to find out the maximum weighted bipartite matching is Hungarian algorithm. This is repeated for the cooperative allocation also. Where the weights are given by

$$\left(B_n(t) - B_m(t)\right)\omega_{mn}^c(t) - X_a^c(t) I_m^a(t)\left(1 - Y_a^c(t)\right)$$

With this we can solve the graph optimally. The steps that should be followed for Hungarian algorithm are:

1. Create a weight matrix.
2. Find the maximum weight from each row and subtract it from all the elements of that row.
3. Find the minimum number of lines required to cover all the zeros it is called minimum vertex cover.
4. If the number of lines required to cover the zeros is equal to the number of rows and columns then the algorithm is terminated.
5. If not then find the least weight which is not covered by the lines and subtract it from uncovered weights. It is added to the weights at the intersection of the lines.
6. Then again find the minimum vertex cover. If it satisfies the condition 4 then the algorithm stops else it goes to step 5.





(a) Matrix
(b) Step 1, 1st iteration
(c) Step 2, 1st iteration
(d) Step 3, 1st iteration
(e) Step 4, 1st iteration
(f) Optimal assignment

Fig. 4. An example is given to show how the algorithm works

The weight matrix is formed using the product of backlogs, capacity and also the binary value that whether the channel is available or not. While doing the simulations all the constraints should be kept in mind [5]. For solving this there are some other methods like cost scaling algorithm, distributed approximation algorithm etc. but Hungarian algorithm is used mainly because it is simple and easy to implement.

6. SIMULATION OF RELAYING SCENARIOS AND STUDY OF RELATING THIS IN THE FEMTO-CELL SCENARIO

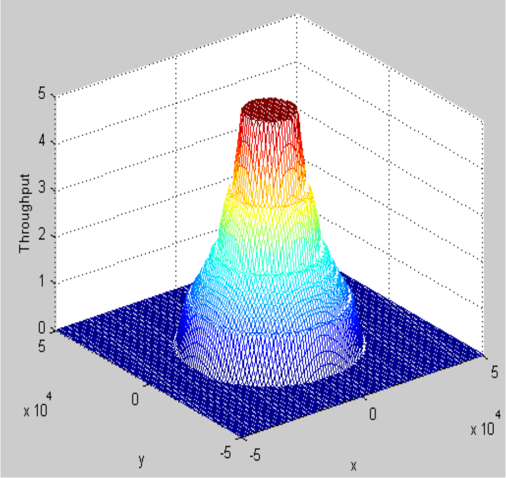


Fig.5. Throughput for no relay scenario

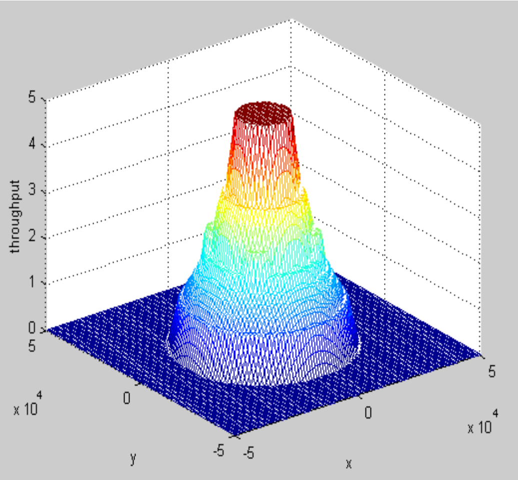


Fig.6. Throughput for simple relay scenario

The Fig. 5, 6, 7 compares 3 scenarios one which has no relay only direct transmission, the other which has simple relay and next with cooperative relaying. Transmission power of the BS was set to be 27.3dB, noise power set to be -130dB, relay transmission power of 17.3dB. [8] The throughput values will be put in the form of a table and SNR value is used to find corresponding throughput from the table. The actual role of relays is to extend the coverage. Cooperative relaying helps in coverage extension along with considerable enhancement in throughput. But requires more spectrum.

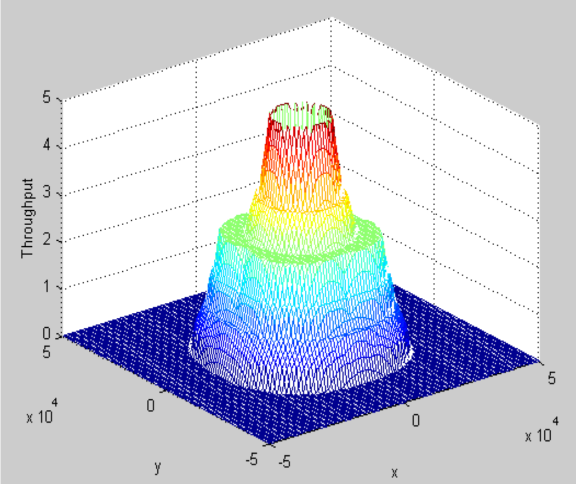


Fig.7. Throughput for cooperative relay scenario

The comparison clearly shows that cooperative relaying is much more efficient than other two. When the SNR of the user is good then we will go for direct transmission and when it is low we use either relaying or cooperative relaying. The disadvantage of this technique is that it increases the signaling overhead which can be reduced by using traffic aggregation. The advantages are much more because in the femto-cell scenario by including relaying technique we can more effectively utilize the spectrum holes. Routing of packets through proper relay terminals is also important. This is done by the following algorithm:

1. The mac acquires the channel information and network parameters
2. Each user builds up a neighbor list and stores relay parameters.
3. For each neighbor it calculates a suitability value as: $S = THRR * BWr/HOPCOUNT$
4. It then finds the relay station or mobile station with the maximum value of S.

Using this algorithm we route our packets to the destination and is shown in Fig. 8. From this it is evident that edge cell users which have low SNR's will be fed via relays. With femto-cells in the scenario channel allocation become complex. For that we go for maximum weighted bipartite graph matching.

7. CONCLUSION

Since mobility in wireless networks is a major requirement femto-cell, relaying and cognitive radio are of great significance. It is evident that integration of cognitive WiMAX and femto-cells is a very complex work. We require rigorous optimization so that the resources are not wasted and spectrum holes. If it is not properly optimized then it will result in packet loss, wastage of spectrum etc. the routing algorithm given above is used in the femto scenario and channels will be allocated accordingly using Hungarian algorithm. In future the femto-BS can also be made cognitive. Thus it may become much more efficient.

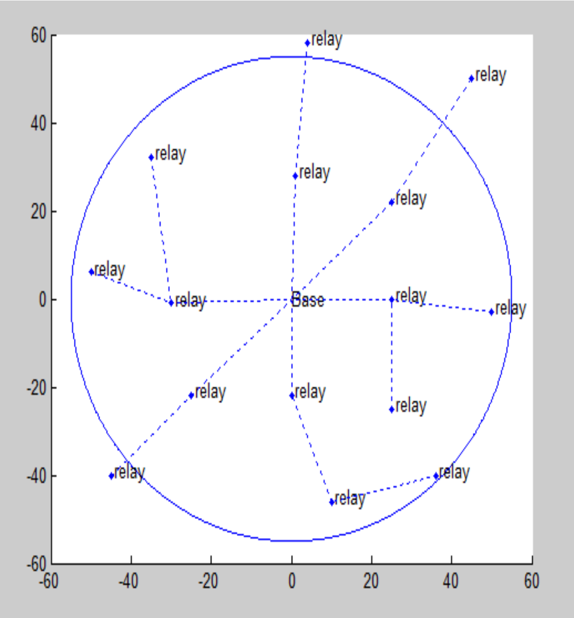


Fig.8. Relay routing scenario

The problem with this technique is that it increases the signaling overhead. So in future we can incorporate some techniques that will reduce the signaling overhead. In future different cognitive technologies like energy detection, cyclo-stationary etc. can be compared for the scenario. We can accept the technique which ever gives less sensing errors, less delay etc.

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