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Backhaul Effect on User Association in cellular and WiFi Networks

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Abstract- The huge growth of data traffic has led to a continuous increase in capacity demands in mobile networks. A cost effective approach is to offload data traffic to WiFi network for enhancing the network capacity and improving the system performance. In this paper, we study the effect of the network backhaul on the selection decision for this network. We are dealing with a single and multi-hop wireless backhaul transmission under different circumstances and different numbers of associated users. One of MADM algorithms which is widely adopted is Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). We use TOPSIS in order to arrange the available networks, according to several metrics and based on the user priorities and requirements. Thus helping for optimum user-network association that will improve the system performance while satisfying the user requirements. The analytical results show the importance of taking the backhaul effect during the user association process and how the backhaul link effects the overall performance.

Keywords- Backhaul, WMN, Cellular network, backhaul delay.

I. INTRODUCTION

The unexpected explosion of mobile data traffic has led to that the cellular networks are overloaded. So, in overloaded areas, the mobile users will have to face degraded services, such as low data rates and low quality of services. A straightforward solution for this is to upgrade the cellular network or deploy more base stations (BSs) in infrastructure, which will increase the network infrastructure cost. A more effective approach is to offload the mobile data to another network or technology. The mobile operators are interested for mobile data offloading

to increase their network capacity while maintaining a good quality of service for users. Currently, many interests are focused on Wi-Fi networks to offload traffic as it uses unlicensed spectrum and can address the traffic demand [1][2]. So, mobile operators can leverage the load from their networks using a low cost and easy to install technology, which is referred to as WiFi offloading [3][4]. It has a few advantages: (1) there is no need for user equipment upgrading since most of the mobile devices already have a built-in WiFi. (2) No licensed spectrum is required. WiFi devices operate in unlicensed 2.4 GHz and 5 GHz bands. (3) High data rates are supported. Different WiFi technologies can support different data rates, e.g. IEEE 802.11n WiFi can deliver data rates as high as 600 Mbps and IEEE 802.11ac can deliver up to 6.933 Gbps [5], which is much faster than 3G. (4) Low infrastructure cost. The WiFi nodes are much cheaper than the cellular BSs.

Therefore, the WiFi offloading becomes a very interested approach for the researchers and operators all over the world. The performance of using WiFi networks to offload 3G mobile data in metropolitan areas was studied in [6]. Different approaches to improve the performance of WiFi offloading were investigated in [7],[8]. The authors in [9] consider WiFi offloading in heterogeneous scenario in order to maximize the user satisfaction in the system with guaranteeing that the user will get a higher rate through WiFi. Papers [10],[11], propose a WiFi offloading algorithms in the multi-

small BS (SBS)-multi-access point (AP) scenario. The algorithm is based on offloading one mobile user with the minimum per-user effective capacity from the SBS to an overlapped WiFi AP which has the largest capacity.

The existing works that deal with WiFi offloading are rarely considering the backhaul (BH) and do not take its effect on network performance. Since the backhaul may be the bottleneck of the network, it should be used as a good metric for taking the offloading decision. The authors in [12], evaluate the throughput performance, offloading efficiency, and in particular, the delay performance of FiWi in heterogeneous networks (HetNets). They include also the impact of various localized fiber-leas backhaul redundancy and wireless protection techniques. They discuss the WiFi offloading limitations due to WiFi mesh node failures as well as temporal and spatial WiFi coverage constraints. The work in [13] present the backhaul wireless link performance modelling and apply it in a user association optimization problem. In [14], they investigate the traffic offloading in backhaul constrained small cell cellular networks. They proposed a network latency aware user association scheme that distributes the loads between BSs to minimize the average traffic delivery latency. The majority of these works are dealing with cellular networks consisting of small cells BSs only while offloading to WiFi network and study their backhaul is not considered. Also, the WiFi mesh network which can be used as a backhaul network for WiFi users is not considered on these works.

In this paper, we study the effect of backhaul networks on the user association and the decision for network selection. We are taking into account the user priorities and requirements in the network selection process. Also, Using the TOPSIS technique for arranging the available networks to the user, and associate him with the best available one to satisfy his requirements and the system quality of service (QoS) performance. We analyze the effect of wireless backhaul and multi-hop

transmission on network selection and data offloading under different circumstances.

The rest of paper is organized as follows. The system model and networks analysis is described in Section II. In Section III, we study the network selection technique with multiple criteria. The performance evaluation is provided in section in Section IV, and conclusion is summarized in Section V.

II. SYSTEM MODEL

Consider a heterogeneous scenario in which there is a macrocell base station (MBS) overlaid with a WiFi Mesh Network (WMN) that covers a specific area and consists of δ APs, as shown in Fig.1. Assuming that the MBS is connected to its core gateway (GW) via a wireless backhaul link, while the WMN is used as a backhaul network for WiFi users. For the WiFi network, each access point (AP) may be a relay for delivering the traffic of another APs in addition to its local traffics owned for its associated users. Therefore, we have a multi-hop communication over WMN for reaching the WMN gateway that is considered in our analysis.

The analysis for backhaul connection behind the GW is neglected since it is common for all APs and is assumed to be an ideal. So, based on the number of contending users, and average number of hops, the delay and throughput analysis for WMN can be evaluated. Assuming that the APs use different bands for access and mesh connection, e.g.2.4GHz for access and 5GHz for backhaul connection over the mesh network. On other hand, the cellular wireless backhaul link is assumed to follow Rician distribution that is suitable for line of sight (LOS) connection. Therefore, our analysis will include the access and backhaul networks of both technologies in order to evaluate its performance. Assuming that a user has data for specific application, with a packet size of P bits, which will be transmitted through a network.

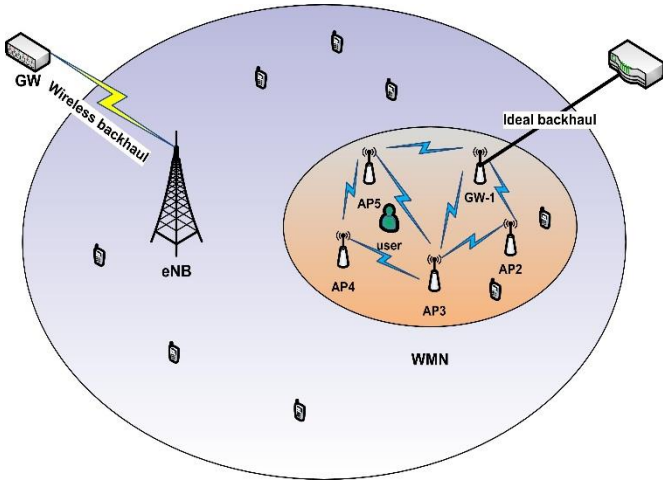


Fig.1. Heterogeneous system model.

A. LTE analysis

For the LTE access network, assuming that each user will be assigned one resource block for data transmission. Then, suppose that n_{LTE} users are associated to LTE cell and we are characterizing the network by calculating its available capacity. Using the number of associated users, we can determine

the available resource blocks and thus the average of available network capacity S_{LTE-r} as

$$S_{LTE-r} = B_R \log_2(1 + \bar{\gamma}_L) \quad (1)$$

where B_R is the bandwidth of available resource blocks and $\bar{\gamma}_L$ is the average signal to noise ratio between the MBS and users, assuming an additive Gaussian noise, for LTE network.

Considering that MBS transmission realizes M/G/1 processor sharing queue, in which multiple users share the radio resources for MBS. Therefore, the average packet delivery time can be defined as

$$T_{LTE} = \frac{P}{S_{LTE}(1-\rho_L)} \quad (2)$$

where S_{LTE} is the LTE system throughput, when the number of n_{LTE} users associated with it. ρ_L represents the traffic load of MBS which is

calculated using the average traffic load for each user associated with it.

For the wireless backhaul link, assuming the transmission is time slotted and one packet is transmitted in each time slot. The transmission succeeds if the received signal to noise ratio (SNR) is above a threshold value θ . Otherwise, the transmission is considered to have failed and retransmission is required. The amount of bits that can be transmitted in a single successful transmission can be defined as

$$b_s = \tau_s B_{bh} \log_2(1 + \theta) \quad (3)$$

where τ_s is the time slot length and B_{bh} represents the bandwidth for backhaul link. Since we are assuming that the signal to noise ratio, γ_{bh} , of wireless backhaul link follows Rician distribution with Rice parameter K , the transmission success probability can be evaluated, using the cumulative distribution function (CDF) of SNR, as

$$\begin{aligned} p_s &= pr(\gamma_{bh} > \theta) \cong 1 - CDF(\theta) \\ &\cong Q_1(\sqrt{2K}, \sqrt{\frac{2(K+1)}{\bar{\gamma}_{bh}}} \theta) \end{aligned} \quad (4)$$

where $\bar{\gamma}_{bh}$ is the average SNR over the backhaul link, and Q_1 represents the first-order Marcum Q function. Therefore, the mean number of transmissions to successfully deliver the packet is in turn $1/p_s$. Finally, this number of transmissions is multiplied by the time slot length to obtain the mean packet delay over the wireless backhaul as

$$T_c^{bh} = \tau_s * \frac{1}{p_s} * \varepsilon \quad (5)$$

where ε is the required number of time slots for transmitting the packet.

B. WMN analysis

For the WiFi access network, there is a contention on the channel to acquire it for data transmission. The channel's contention degree is determined

according to the number of users associated with AP which is reflected as a collision between them. Suppose that we have a WiFi AP k and n_w^k users associated with it thus having $n_w^k + 1$ stations contending on the channel assuming that the AP and users always have data to be sent. Each AP k has a saturation point, where its system capacity is utilized, and the number of users at this point is denoted by n_{sat}^k . Note that, the saturation level for each AP is determined based on its characteristics and the technology used. Therefore, we can calculate the average user throughput at the saturation point over WiFi AP k using Bianchi's model as [15]

$$R_{sat}^k = \frac{P_{sw}^k P_{tw}^k P / n_{sat}^k}{(1 - P_{tw}^k)\sigma + P_{sw}^k P_{tw}^k T_{sw} + (1 - P_{sw}^k) P_{tw}^k T_{cw}} \quad (6)$$

Where $P_{tw}^k = 1 - (1 - \tau_{kw})^{n_{sat}^k + 1}$ is the probability that there is at least one transmission in a slot time, and probability $P_{sw}^k = (n_{sat}^k + 1) \tau_{kw} (1 - \tau_{kw})^{n_{sat}^k} / P_{tw}^k$ that a transmission is successful at which τ_{kw} is the probability that the station transmits a packet in a random slot time. The parameters σ , T_{sw} , T_{cw} are the duration of empty slot time, the average time the channel is sensed busy due to a successful transmission, and the average time the channel is sensed busy during a collision, respectively. Considering that the WiFi system is managed via the request-to-send and clear-to-send RTS/CTS access method so, we can obtain the values of, T_{sw} , T_{cw} [15]. Therefore, on AP k , by calculating the allowable number of users for association, we can determine the available WiFi system capacity by

$$S_{W-r}^k = (n_{sat}^k - n_w^k) * R_{sat}^k \quad (7)$$

Therefore, considering the WiFi AP as a processor sharing queue, the average packet delay over WiFi AP k can be determined by

$$T_w^k = \frac{P}{S_w^k (1 - \rho_w^k)} \quad (8)$$

where S_w^k is the system throughput of AP k , when the number of n_w^k users associated with it, which is also calculated using Bianchi's model. ρ_w^k represents the traffic load of WiFi AP k .

For WMN, the contention will be between the APs that construct the mesh network and visible to each other. For simplicity, we assume that a predefined static routing is applied for different paths on mesh network thus, for each AP k , the number of hops which is denoted by H_k , to reach the gateway, will be known. For AP k which has a certain number of users, each user with arrival rate λ_w , the total arrival load ρ_m^k which is consisting of the local and relayed traffics, on this AP can be evaluated. Therefore, the average packet delay, T_m^k , over a certain hop can be determined by

$$T_m^k = \frac{P}{S_m^k (1 - \rho_m^k)} \quad (9)$$

S_m^k represents the throughput of AP k on the backhaul layer that will be calculated using Bianchi's model as [15],

$$S_m^k = \frac{P_{sm}^k P_{tm}^k P}{(1 - P_{tm}^k)\sigma + P_{sm}^k P_{tm}^k T_{sm} + (1 - P_{sm}^k) P_{tm}^k T_{cm}} \quad (10)$$

The contention in mesh network will be between the neighboring APs that have an intersection in coverage with AP k , i.e. having a link with each other for transmission. Thus, the parameters P_{sm}^k , P_{tm}^k , and collision probability are calculated based on the number of contending APs, and determining the total path delay from the first AP k along the path ($z = 1$) to the gateway through H_k hops as following

$$T_t^{k-G} = \sum_{z=1}^{H_k} T_m^z \quad (11)$$

III. SELECTION TECHNIQUE

We use TOPSIS technique for network selection which is widely used as MADM algorithm. TOPSIS ranks the available networks based on their scores, with the highest being the best. In our model, suppose that the networks are represented by MBS as LTE network and independent WiFi APs each construct a network with its own characteristics.

The networks which represents the alternatives of the problem are denoted by $N = \{N_i, i = 1, 2, \dots, q\}$, where N_1 denotes the LTE MBS and (N_2, \dots, N_q) represents the different WiFi APs. The set of attributes, or criteria, that characterizes the network is denoted by $A = \{A_j, j = 1, 2, \dots, d\}$, each has a value X_{ij} . These attributes have a weight vector $W = \{W_1, W_2, \dots, W_d\}$, that is satisfying $\sum_{l=1}^d W_l = 1$, this can be represented in table 1.

The TOPSIS algorithm is applied for network selection as follows:

1: The value of each attribute is normalized as follows

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^q x_{ij}^2}} \quad (12)$$

2: The matrix is updated with the normalized values.

3: Using the weight for each attribute, construct the weighted normalized matrix as

$$v_{ij} = W_j * r_{ij} \quad (13)$$

4: find the best and the worst value for each attribute, if the attribute is desirable then the higher value is the best (e.g., throughput), and if the attribute is undesirable (e.g., delay) then the lower value is the best.

- For desirable criteria

$$V_j^+ = \max\{v_{ij}\} \quad \text{and} \quad V_j^- = \min\{v_{ij}\} \quad (14)$$

Table.1. TOPSIS matrix.

	A_1 (W_1)	A_2 (W_2)	...	A_d (W_d)
N_1	X_{11}	X_{12}		X_{1d}
N_2	X_{21}	X_{22}		X_{2d}
.				
N_q	X_{q1}	X_{q2}		X_{qd}

- For undesirable criteria

$$V_j^+ = \min\{v_{ij}\} \quad \text{and} \quad V_j^- = \max\{v_{ij}\} \quad (15)$$

5: Measure the distances for both the best and worst cases.

$$D_i^+ = \sqrt{\sum_{j=1}^d (v_{ij} - V_j^+)^2} \quad (16)$$

$$D_i^- = \sqrt{\sum_{j=1}^d (v_{ij} - V_j^-)^2} \quad (17)$$

6: Calculate the coefficient C using the distances D from the best and worst solutions by:

$$C = \frac{D_i^-}{D_i^- + D_i^+} \quad (18)$$

7: Select the network with the highest C value.

In our model, we use four attributes, $d=4$, which are used for the network selection. These criteria are, the available network capacity, total delay which is consisting of access with the backhaul delays, the cost per byte on each network, and the network's security level. Using these characteristics, we can evaluate each available network and select the best network for satisfying the user requirements. Each user specifies his own priorities by assigning the weight vector W .

IV. PERFORMANCE EVALUATION

We will investigate the effect of backhaul on network performance. Two different radio access technologies are considered, LTE MBS and different WiFi APs. We assume that the mesh network is consisting of five APs, $\delta = 5$, all of them are using the same technology, IEEE 802.11g, and adopted with access frequency 2.4 GHz that differs from the mesh link which is operating at frequency 5GHz. The network parameters are listed in table 2.

Considering a scenario in our system, where a user is located in a region under coverage of the MBS and three different APs, i.e. AP1, AP2 and AP3. The number of associated users to MBS and three APs is as follows, {50, 7, 11, 12}, respectively. The objective is to select the best network which is satisfying the user requirements. Based on previous analysis and knowing the number of associated users and their average load, we evaluate the available capacity of the network and the average packet delay with considering the backhaul for this network. Each user takes one resource block on LTE network or contend on the channel over WiFi network. The weight vector for the user is adopted to be $W = \{0.3 \ 0.4 \ 0.2 \ 0.1\}$, where the largest weight is given to the delay metric, 0.4, while 0.3 is given to the available capacity metric, and 0.2, 0.1 are given for the cost and security, respectively.

The TOPSIS technique is applied using the specified parameters and analysis, in order to select the suitable network for association taking into account the effect of the network backhaul on selection process. As shown in table 3, when taking the backhaul packet delay into consideration and according to the specified network parameters and conditions, the LTE MBS network will have the best performance. The MBS has the highest score C , under specific conditions and certain number of users. So, the user will associate to MBS with guaranteeing its delay and throughput requirements. The LTE MBS has an average packet delay on access plus backhaul links, 0.49ms and 13.838 Mbps available capacity. The cost for the networks is measured in pound/Mbyte, £/MB, and assign

TABLE 2. Network Parameters.

LTE parameters	Values
Macrocell Bandwidth	20 MHz (100 RB)
Resource block bandwidth	180 KHz
Rice parameter K	5
Packet size	1500 Byte
Wi-Fi parameters	Values
Bandwidth	20 MHz
Wi-Fi technology	802.11g
Data rate	54 Mbps
Minimum contention window(W)	16
Maximum number of re-transmissions (m)	6
Slot time	9 μ s
DIFS	50 μ s
SIFS	10 μ s

a security level of 1 or 2, with 2 refers to a higher network security. Table 4, shows the selection process without considering the backhaul into analysis and selection. As shown, the selected network is changed to be AP1, that gives the best performance when considering only its access network and neglecting the backhaul. Thus, the LTE MBS will be ranked as the second network after AP1.

Fig.2. shows the effect of backhaul on the network selection and system performance. When considering the backhaul link, the average of total delay (access + backhaul) for each network is determined and used in selection process thus, selecting the network which is optimize the total delay performance, LTE will be chosen in our case. Without considering the backhaul, the wrong network maybe chosen, AP1 in this case, that appears in selection process with a better delay performance compared to other networks but actually it will be with a bad performance due to the presence of backhaul delay which is not considered in selection as shown in Fig.2. The figure also shows the delay performance with the increase of average user arrival rate in packet/sec.

Fig.3.shows the effect of backhaul SNR on the LTE network ranking. As the SNR over backhaul link increases, the average packet delay over it will be decreased, and thus increases the network ranking toward the best as shown in figure.

Table.3. TOPSIS network selection considering the network backhaul.

Network	Available capacity		Delay		Cost		Security		
	C	Mbps	norm	Ms	norm	£/MB	norm	level	norm
LTE MBS	0.6509	13.838	0.721	0.49	0.146	4	0.917	2	0.756
AP1	0.4897	11.278	0.587	2	0.59	1	0.229	1	0.378
AP2	0.3632	5.639	0.293	2.2	0.657	1	0.229	1	0.378
AP3	0.4530	4.229	0.22	1.5	0.444	1	0.229	1	0.378

Table.4. TOPSIS network selection without considering the network backhaul.

Network	Available capacity		Delay		Cost		Security		
	C	Mbps	norm	Ms	norm	£/MB	norm	level	Norm
LTE MBS	0.583	13.838	0.721	0.325	0.28	4	0.917	2	0.756
AP1	0.603	11.278	0.587	0.622	0.536	1	0.229	1	0.378
AP2	0.445	5.639	0.293	0.649	0.559	1	0.229	1	0.378
AP3	0.417	4.229	0.22	0.657	0.566	1	0.229	1	0.378

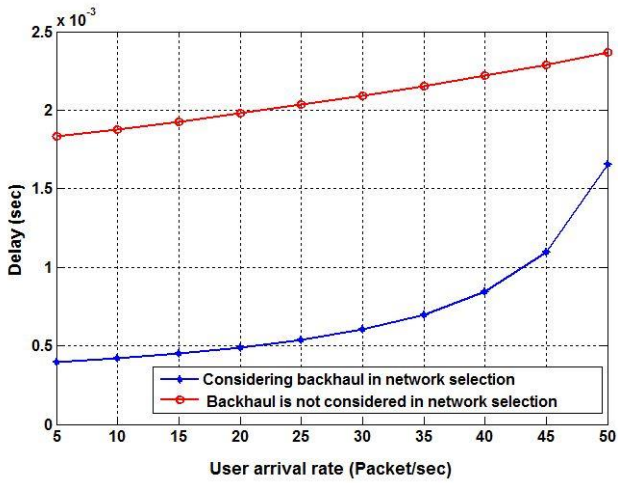


Fig.2. Average packet delay considering the backhaul and without considering it.

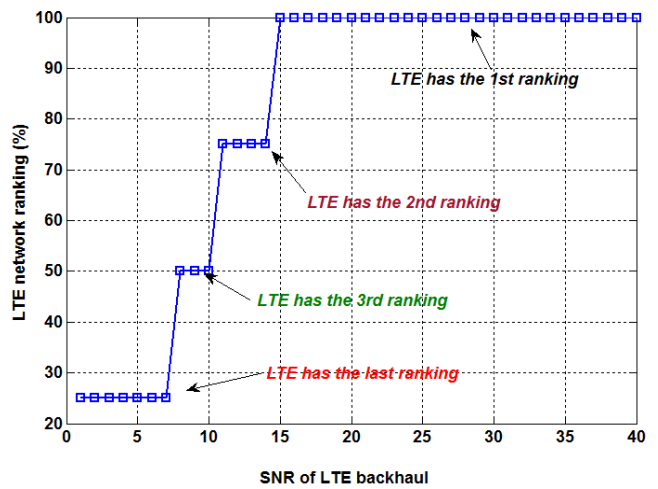


Fig.3. The effect of backhaul SNR on LTE network ranking.

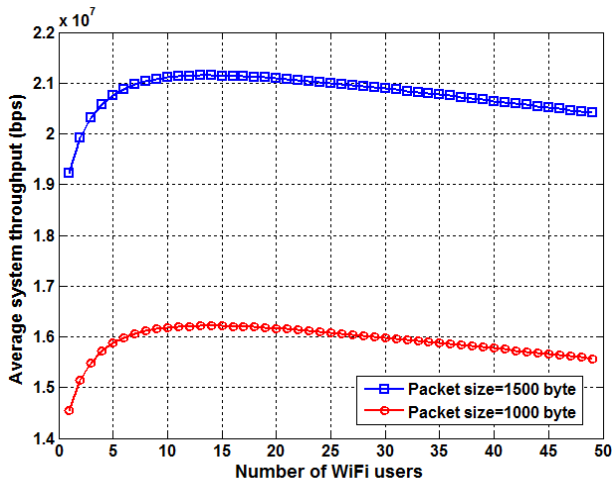


Fig.4. Average throughput of WiFi AP variation with the number of WiFi users.

The ranking 100% means this network is the best performance one and ranked as the first. The ranking decreases until 25% for the worst and last ordered network as shown in Fig.3.

Fig.4. shows the variation of average throughput of WiFi AP with the number of associated users. There is a contention on WiFi channel between the users that may cause packet collisions and a number of retransmissions that all influence the system throughput.

V. CONCLUSION

In this paper, we consider a scenario where a user is located in coverage of different networks, i.e. LTE MBS and different WiFi APs, each has its own characteristics. Our selection technique, TOPSIS, considers the average backhaul packet delay through the networks arranging process. The criteria which used for selection are, the available capacity for each network, the average total packet delay taking the network backhaul into consideration, the cost per byte, and the security level for each network. The results show the importance of backhaul network and how a wrong selection for a network may happen in case of neglecting the effect of backhaul that may deteriorate the system performance and increases the user latency.

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