Performance Improvement of Data Offloading using Multi-rate IEEE 802.11 WLAN

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ABSTRACT:
The WiFi offloading has emerged as a solution to mitigate the surge of traffic in cellular networks. The design of WiFi networks and the placement of Access Points (APs) has a considerable impact on the overall performance and the corresponding capital and operational expenditure (CAPEX/OPEX). Therefore, the minimum required number of APs without severe performance degradation is one of the challenges in WiFi offloading. In this paper, we investigate the impact of multi-rate WiFi APs on the offloading performance. A numerical analysis is presented to compare the minimum required number of APs in two modes of single-rate and multi-rate of IEEE 802.11 WLAN. The analysis results indicate the privilege of multi-rate WiFi AP when compared to single-rate WiFi AP. Moreover, the evaluation results show that required WiFi APs in multi-rate are 30% less than single rate WiFi APs.

KEYWORDS: Offloading, WiFi APs, Single-rate, Multi-rate, Throughput.

1. INTRODUCTION

The rapid increase of data traffic has recently appeared as the main challenge of cellular network operators. The traffic growth rate of the data transmitted in the network is annually 61% while the growth rate of the network deployment is 36% [1]. Widespread use of mobile smartphones and using applications on these phones, including audio, video or other data, provide high traffic information. This growth results in heavy pressure on two parts of the cellular network: The radio access network and the core network infrastructure [2].

The main concerns of operators are quality of service provided to users and the inevitable investment of network development. Thus, they investigate novel approaches which mitigate the surge of traffic in cellular networks. The collaboration between some well-known operators and vendors result in a standardization of a new approach called *mobile data offloading* [3]. In this approach, the unused bandwidth of a complementary wireless technology is employed for mobile users inside the cellular networks. Through the spectrum efficiency provided by this approach, the key performance indicators of cellular networks are improved even in high data traffic.

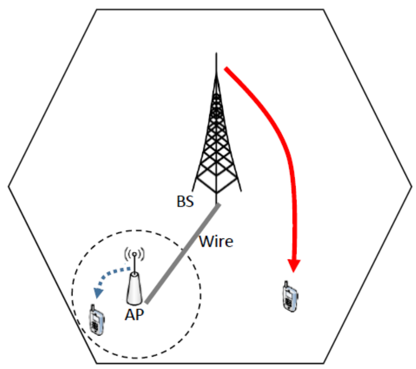

Fig. 1. A WiFi Offloading Scenario.

Although the complementary network can be any wireless technology, current academic and industrial research mostly concerns with WiFi networks. Thus, in WiFi offloading, the unused spectrum of WiFi networks is used to transfer data originally planned to flow through the cellular network. There exist some special features in WiFi networks which provide the WiFi offloading as the most promising approach: The vast deployment of WiFi Access Points (APs) in every place, provision of indoor coverage, quickly and easily deployment, and wide use of WiFi enabled smart phones. In addition, Internet access services through the WiFi networks is cheaper and faster than Internet access through the cellular networks. However, there exist some constraints in WiFi networks such as limited coverage of APs and user mobility. This constrains pose a design problem in an overlay network including APs and cellular Base Station (BS).

In an overlay network (Fig. 1), every mobile user within an AP coverage area might use it as an alternative to BS during the data exchange. The coverage of IEEE 802.11 standard is in the range of 30-100 meters while the cellular BS is designed to cover the larger range of 0.5-1 km in urban areas, and 2-6 km in rural areas. In contrast, the WiFi AP provides the transmission rate more than 3 times than cellular technologies (e.g. LTE) [4]. The BS is connected to AP by a coaxial link or an optical fiber. Clearly, the number and the locations of APs have impacts on the performance of WiFi offloading. In this paper, we investigate the performance of the WiFi offloading when the multi-rate WLAN is employed in WiFi APs. Moreover, we will determine the minimum required APs in multi-rate WLAN scenario.

The rest of the paper is organized as follows: Section 2 discusses the state-of-the-art of existing algorithms for WiFi cell deployment. A system model for multi-rate WLAN in the overlay network is described in Section 3. In Section 4, we present the analysis results of our scheme in IEEE 802.11n standard and LTE. Section 5 concludes the paper and presents potential directions for future works.

2. RELATED WORKS

The APs' deployment in WiFi offloading is influenced by two types of applications: Non-delayed and delay tolerant applications. In a non-delayed application such as voice over IP (VoIP) and interactive audio and video streams, there exist some hard delivery delay constraints to preserve the quality of service (QoS) requirements. In contrast, the delay tolerant applications such as E-mails, news-related information and podcasts may sustain a certain degree of delay without breaking user satisfaction. Due to different requirements of these applications, there exist two categories of algorithms to place optimally the APs in order to maximize the traffic that flows through the alternative channel. In this section, we provide an overview of algorithms which determine the optimal positioning of APs and the minimum required number of APs.

In none-delayed offloading, optimal APs' deployment would be a principle solution for improving the performance of real-time data offloading. One of the first studies on the QoS improvement of non-delayed offloading was performed in [5]. The authors proposed three AP deployment algorithms: traffic-centric, outage centric, and random uniform. The first and the second algorithms aim to improve the average throughput and network outage, respectively. The analysis and simulation results of an indoor scenario without the mobility indicate a direct proportional relationship between the average throughput and the density of APs. Another approach of APs' deployment algorithms was proposed in [6] and [7] which focuses on maximizing the fraction of offloaded traffic. The idea is to find the locations with a high density of mobile data traffic (or mobile users) to place the APs. The analytical models and simulation results indicate 20-70% of diverted traffic to WiFi networks depending on the AP density. In an analytical model proposed in [8], the performance of none delayed offloading was studied for real-time applications. The expected delivery delay is obtained as a function of the AP availability, the traffic request rate and the data rate of two networks. In a similar work [19], the probability of congestion at APs is evaluated when the maximum number of users achieve the maximum data rates.

In the delay tolerant offloading, AP deployment is investigated when the delay constraints satisfy the required conditions for delay tolerant applications. Generally, the end-users should receive content within the deadline. The authors of [10] demonstrate the improvement of offloading ratio by enlarging the delay tolerant content. Moreover, the simulation results indicate that the completion time of delay tolerant offloading is much lower than the maximum deadline. In another research work [11], an analytical model was proposed to obtain the delay bounds of delay tolerant offloading. By exploiting the queuing theory, mean reception delay and offloading efficiency are evaluated as a function of users and APs' availability. By proposing a greedy algorithm in [12] and a genetic algorithm in [13], the optimal AP positions for information dissemination in the delay tolerant offloading were determined. In the first algorithm [12] which is called Drop zone, both the number of APs and the average uploading delay have reduction. The second algorithm [13] which considers an offloading in a vehicular environment, the optimal AP deployment is investigated. The issue of offloading in vehicular networks was also followed by another research works [14], [15]. By employing the minimum number of APs in [14], the probabilistic connection time is guaranteed. The underlying intuition in [15] is to employ the parked vehicles as additional APs to assist in data distribution and to improve the AP availability.

Nevertheless, none of the existing works did not consider the impact of physical layer features of WiFi networks on the performance of offloading. In this paper, we employ a multi-rate WiFi AP and we investigate its influence on the performance of a WiFi offloading and the minimum required number of APs. A similar work was presented in [16] which a single-rate WiFi AP is deployed.

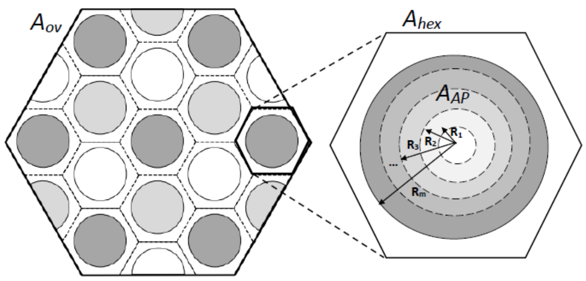

Fig. 2. An overlay network with multi-rate WiFi AP.

3. SYSTEM MODEL

In this section, we use the analytical model to calculate the user throughput and the minimum required number of APs. We use the modulation and coding scheme 1 (MCS1) of IEEE 802.11n standard as the multi-rate WiFi AP and LTE network as the cellular technology. We investigate the impacts of both the multi-rate WiFi AP and the single-rate WiFi AP on the performance of WiFi offloading.

Similar to [16], we consider a geometrical system model of a regular hexagonal cell (RHC) for each WiFi cell (Fig. 2). Every user transfers data through the WiFi networks as it moves in the coverage of one AP. When it moves out of WiFi coverage, the offloading is discontinued and the data transfer is performed through the cellular connectivity. In the multi-rate WiFi AP, as the distance between the user and AP (Ri) increases, its data rate (DRi) decreases. Since each data rate has its own transmission range, each user selects a corresponding data rate according to its distance to AP. The MCS1 of IEEE 802.11n standard provides 8 data rates of $DR_1>DR_2>\dots>DR_8$ with corresponding ranges of $R_1<R_2<\dots<R_8$.

If the users are uniformly distributed within the coverage area of a cellular BS, we have assumed an average number of $n=\frac{N_W}{K}$ in each AP coverage (A_{AP}). Where, N_W and K are respectively the total number of users in WiFi coverage and the number of WiFi APs. Due to uniformly distribute of users and according to Eqn. (1) in [16], the proportion of WiFi users to all users can be expressed as:

$$\eta=\frac{N_w}{N_{ov}}=\frac{A_{AP}}{A_{hex}}. \tag{1}$$

Where, N_{ov} and A_{hex} denote the total number of users in cellular coverage and the hexagonal encompassing the AP coverage, respectively. By performing the power control, it is possible to adjust the AP coverage between zero to A_{hex} (e.g. $0<\eta<1$).

To analyze the WiFi throughput, we use the Markov chain model in [17] which provides DCF mechanism modeling. We assume the Request-To-Send/Clear-To-Send (RTS-CTS) mode for our analysis. In DCF mode, the probability that a node transmits a packet in a particular time slot is expressed as:

$$\tau=\frac{2}{CW+1} \tag{2}$$

Where, CW is the contention window. When a network has n nodes, the probability that there is at least one node transmitting a packet in a given time slot (P_{tr}) can be calculated as:

$$P_{tr}=1-(1-\tau)^n \tag{3}$$

Since only one node sends packet in a given time slot, the probability of successful transmission in that time slot (P_s) will be

$$P_s=\frac{n\tau(1-\tau)^{n-1}}{P_{tr}} \tag{4}$$

For a successful transmission, the expected transmission time in multi-rate mode can be expressed as

$$T_s=\sum_{i=data\ rates} f_i t_i\,. \tag{5}$$

Where, f_i and t_i denote the proportion of users having a data rate of DR_i and its successful time in RTS-CTS mode which can be expressed, respectively as follows:

$$f_i=\begin{cases}\frac{R_i^2}{R_n^2}. & i=1\\ \frac{(R_i^2-R_{i-1}^2)}{R_n^2}. & i\neq 1\end{cases} \tag{6}$$

$$t_i=T_{RTS}+T_{CTS}+\frac{L}{R_i}+T_{ACK}+T_{SIFS}+4\sigma+T_{DIFS}. \tag{7}$$

Where L is the packet size, and σ is the propagation delay. Clearly, for the single-rate WiFi AP, R_i is replaced by a fixed data rate. If the collision happens, each node senses that the channel is busy, and the collision time T_c is calculated by

$$T_c=T_{RTS}+\sigma+T_{DIFS} \tag{8}$$

Then, the throughput of a single AP in IEEE 802.11 can be expressed as follows:

$$S_W^{AP}=\frac{P_sP_{tr}L}{(1-P_{tr})\sigma+P_{tr}P_sT_s+P_{tr}(1-P_s)T_c} \tag{9}$$

By applying $n=\frac{N_w}{K}=\frac{\eta N_{ov}}{K}$, S_W^{AP} in Eqn (9) can be expressed as a function of K, N_{ov} and η and according to

[16], average per-user WiFi throughput and average per-user cellular throughput can be calculated as:

$$S_W^{user} = \frac{S_W^{AP}(K.\eta.N_{ov})}{N_w} = \frac{S_W^{AP}(K.\eta.N_{ov})}{\eta N_{ov}} \quad (10)$$

$$S_C^{user} = \frac{S_C}{N_C} = \frac{S_C}{(1-\eta)N_{OV}} \quad (11)$$

To decide on selecting the WiFi offloading mode, we need to compare the average per-user WiFi throughput and average per-user cellular throughput. If the WiFi throughput is more than cellular throughput, the user selects the closest WiFi AP. Otherwise, it continues the data transfer through the cellular BS. In the optimal scenario, we find the minimum number of AP (e.g. K) which satisfies the offloading condition as follows:

$$K^* = \arg\min_K S_W^{user}$$
$$subject\ to\ S_W^{user} \geq S_C^{user} \quad (12)$$

In the following section, we will present the results of per-user throughput and minimum required number of APs in two modes of single-rate WiFi AP and multi-rate WiFi AP for IEEE 802.11n as the WiFi standard and LTE as the cellular standard.

4. ANALYSIS RESULTS

In this section, we present the results of our analysis by using MATLAB. Since we use a multi-rate WiFi in our analysis, Table 1 presents the data rates of IEEE 802.11n and their transmission ranges for Modulation and Coding Scheme- Index 1 (MCS1) when BER=10-5. The setting parameters of cellular and WiFi networks are indicated in Table 2. The results present the average per-user throughput of two modes of the single-rate WiFi AP and the multi-rate WiFi AP.

As indicated in Fig. 3, the average per-user throughput is obtained for different numbers of users (100 < Nov < 1000) and different number of APs (K=10, 14, 18, 22, 26, 30) when the proportion of WiFi users to total users is 0.7 (η=0.7) in the single-rate WiFi APs. The fixed data rate of 7.2 Mbps is assumed for the whole coverage area of the WiFi AP. The corresponding per-user WiFi throughput of K* is S_W^{user*}in Eqn (12). For small K , the high contention between users with a fixed data rate leads to low throughput (less than S_W^{user*}) . Therefore, the users transfer data through the cellular BS and the WiFi offloading is not active. The larger K results in fewer users in each AP's coverage, less contention and thus higher throughput. In this case, the WiFi offloading is active for those users within the AP's coverage and the others exchange data through cellular BS.

Similarly, the average per-user WiFi throughput for multi-rate IEEE 802.11n is indicated in Fig. 4. The comparison between Fig. 3 and Fig. 4 demonstrates that the average per-user throughput in multi-rate mode is improved. Although some K values (such as K=25, 30) provide less per-user throughput than S_W^{user*} in single-rate mode, their corresponding per-user throughput increases in multi-rate mode. This improvement is indicated as the minimum required number of WiFi APs for both modes (Fig. 5). By using multi-rate mode, the AP provides a data rate which is a multiple of single-rate (2 to 10) for in each transmission range. The higher data rate provides higher throughput. Thus, the multi-rate mode provides less minimum required APs in comparison to single-rate mode.

Table 1. Data rates and transmission ranges of IEEE 802.11n –MSC1.

IEEE 802.11n data rate	Range (meter)
7.2	115
14.4	91
21.7	78
28.9	62
43.3	46
57.8	34
65	31
72.2	29

Table 2. Simulation parameters.

Parameters	Values
BS cell radius	500m
LTE capacity (Mbps)	56.4
Slot Time (μs)	9
SIFS (μs)	10
DIFS(μs)	28
RTS (μs)	38.89
CTS (μs)	32.23
HTS (μs)	32.23
ACK(μs)	32.23
PLCP (μs)	16.67
MAC header (bits)	272
Single date rate (Mbps)	7.2
CWmin (SlotTime)	15
CWmax (SlotTime)	1023

To evaluate the effect of power control on the WiFi offloading performance, we calculate the throughput for both WiFi modes. By power control, we change η (0.1 to 0.9) for a constant number of users (Nov=200) and different number of APs (Fig. 6 and Fig. 7). As expected, multi-rate WiFi AP provides better throughput than single-rate WiFi AP. This privilege of multi-rate WiFi APs leads to reduction of the required number of WiFi

APs (Fig. 8). This reduction is considerable when the coverage area of WiFi AP approaches the hexagonal area.

5. CONCLUSIONS

In this paper, we investigated the impact of the multiple modulation and coding scheme (MCS) levels on the WiFi cell deployment and WiFi offloading performance. By using the MCS1 of multi-rate IEEE 802.11n and LTE cellular technology, the performance of WiFi offloading and the minimum required of WiFi APs were studied. By applying the multi-rate mode of WiFi AP to numerical analysis in [16], we demonstrated that the multi-rate WiFi AP provides better performance than the single-rate WiFi AP. This privilege is obtained in two scenarios 1) changing of total users and number of APs, with fixed η, and 2) changing the AP coverage area and number of APs, with fixed Nov.

For future works, we will consider the impact of novel techniques on the performance of WiFi offloading. The cooperative WiFi protocols can be one of the solutions which provide better performance. Moreover, analysis of WiFi offloading can be performed in practical circumstances such as real traffic patterns, fixed number of APs and the existence of hidden and exposed nodes.

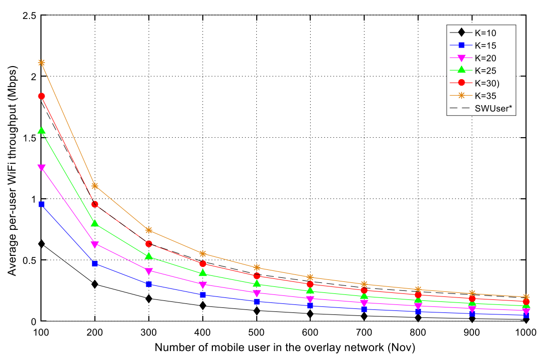

Fig. 3. Average per-user WiFi throughput with single-rate WiFi APs and η=0.7.

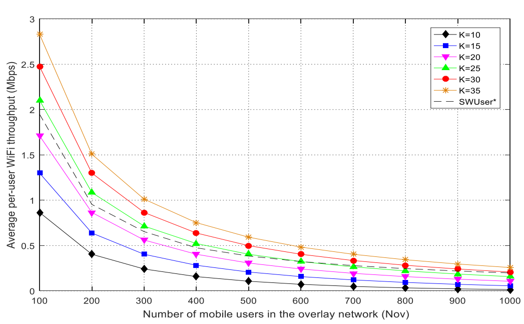

Fig. 4. Average per-user WiFi throughput with multi-rate WiFi APs and η=0.7.

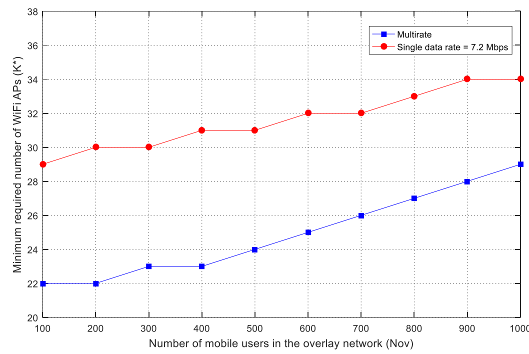

Fig. 5. The minimum required number of APs in two modes of single-rate and multi-rate WiFi AP with η=0.7.

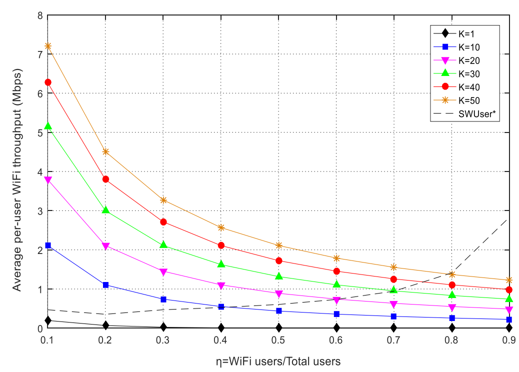

Fig. 6. Average per-user WiFi throughput with single-rate WiFi APs with Nov=200.

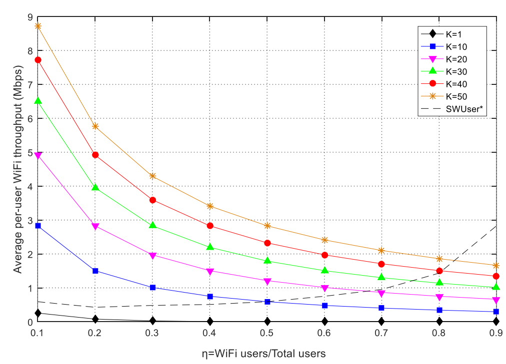

Fig. 7. Average per-user WiFi throughput with multi-rate WiFi APs with Nov=200.

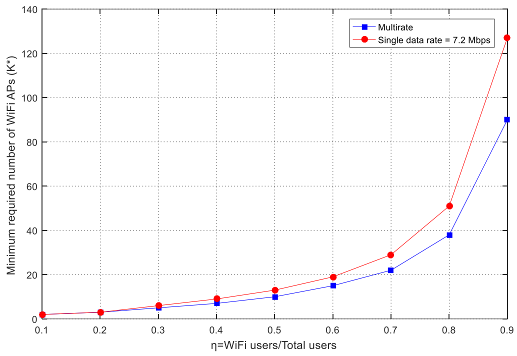

Fig. 8. The minimum required number of APs in two modes of single-rate and multi-rate WiFi AP with Nov=200.

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