Relay-based Cooperation in Mobile Data Offloading

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Relay-based Cooperation in Mobile Data Offloading

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Abstract-

Mobile data offloading has been emerged as a promising solution to manage high data traffic imposed by mobile users. This technique exploits the frequency spectrum of some overlapping networks such as WiFi in cellular networks. Deployment of minimum WiFi access points (APs) is the main challenge in mobile data offloading which leads to the low cost of CAPEX and OPEX. In this paper, we investigate the impact of a relay-based cooperative MAC protocol on the spectrum efficiency of mobile data offloading and consequently on the WiFi APs deployment. Two algorithms are presented to compute the throughput gain and the minimum number of WiFi APs in two modes of cooperative and non-cooperative MAC protocols. The analytical results indicate that the cooperative MAC protocol can provide a reduction of up to 44% in the number of WiFi APs in comparison to non-cooperative mode.

Index Terms- **LTE, Offloading, WiFi, DCF, Cooperation, Throughput.**

I- Introduction

The rapid development of wireless access technology and the increased use of smartphones, tablets, and laptops have led to a considerable increase in mobile traffic, while cellular network infrastructure is not able to provide enough resources for this traffic volume. This sudden growth of cellular data traffic in the world is expected to grow to 49 Exabytes by 2021 [1]. In order to manage this traffic demand, the data offloading technique facilities the use of overlapping heterogeneous networks [2]. The IEEE802.11-based Wi-Fi networks can be a prominent candidate as the complimentary access technology for cellular networks. In the overlapping areas of the cellular network and Wi-Fi network, users can transfer their traffic from the cellular network to the overlapping Wi-Fi network [3]. However, the main challenge is how to deploy the minimum number of WiFi access points (APs) to achieve one or more performance objectives.

There exist several objectives which are investigated in WiFi APs' deployment. Wireless coverage is the first objective which was improved by a purely mathematical model in [4] to find the optimal number of APs and their locations in an indoor scenario. The objective function in this paper is based on one condition in which the path loss between the APs and each receiver node should be less than the tolerable path loss in the indoor scenario. The second objective is the offloading ratio which was investigated by Bulut et al. [5] and Kim et al. [6]. In [5], a greedy heuristic-based algorithm was presented to find the optimal placement of a limited number of APs when the location and data request frequency of users are available. Moreover, it was demonstrated that the greedy algorithm is very close to the optimum and its offloading ratio is more than Sequential [7] and HotZones [8] algorithms with the same AP count. The authors of [6] investigated the offloading ratio of 50% between 3GPP Long Term Evolution (LTE) and WiFi network when the objective was to find the minimum number of APs. In this paper, the coverage area of each WiFi AP is varied and it provides a single data rate that is not compatible with practical scenarios. Moreover, Khoshnoudi et al. [9] developed the analysis of [6] in a practical approach using the multi-rate IEEE 802.11n model and the evaluation was compared to the single rate IEEE 802.11n. In the third objective of AP's deployment, the fingerprinting difference was exploited as a pattern recognition process. For instance, Meng et al. [10] proposed an AP's development approach to render the indoor positioning accuracy based on the received signal strength (RSS) Euclidean distance. Besides the researches which focuses on one objective in AP deployment, the combination of multiple objectives is the main approach in some works [11]-[12].

One of the well-known techniques which provides the spectrum efficiency has been relay-based cooperation [13]. The relay-based cooperation exploits a relay node located in neighborhood area of both source and destination nodes in order to replace one two-hop communication (source-relay-destination) instead of one single hop communication (source-destination) when the relay provides more efficiency in terms of spectrum, energy and other performance metrics [13]. In this paper, a relay-based cooperative protocol in MAC layer (CoopMAC [14]) is employed in WiFi networks and its performance is analyzed and compared with the DCF protocol in non-cooperative mode. Moreover, the deployment of WiFi APs is investigated in two modes of cooperation and non-cooperation scenarios.

2- System model and problem formulation

To analyze the offloading with the cooperation and non-cooperation schemes, we need a system model. As indicated in Fig.1, some user equipment (UEs) have two access technologies (WiFi and LTE) and the others have only access to LTE through the eNodeB. In WiFi coverage, two modes of communication are possible: 1) Conventional WiFi which uses DCF protocol for communication between UE and AP, and 2) Relay-based cooperative WiFi which exploits a two-hop communication between UE and AP through a relay node. The selection of the relay node and the control packets to perform the cooperation are according to the CoopMAC protocol [14]. One UE providing the minimum delay for two-hop communication will be the best relay node.

We consider an LTE hexagonal cell with radius $\mathcal{R}_C$ and different number of WiFi APs which are denoted by the set $\mathcal{K} = \{1,2,\dots,k_{max}\}$ and at known locations given by $\{w_k\}_{k\in\mathcal{K}}$ where $w_k \in \mathbb{R}^{2\times 1}$ represents the coordinates of k-th AP in a two-dimensional plane. Every WiFi AP provides t data rates $\mathfrak{D} = \{d_i\}_{i=1}^{t}$ at different ranges $\mathcal{R} = \{r_i\}_{i=1}^{t}$ where $d_1 < d_2 < \cdots < d_t$ and $r_1 > r_2 > \cdots > r_t$. Since the WiFi area is a circle, we define a hexagonal circumscribed to the circle and the users located between the circle and the hexagonal are served by LTE. The maximum number of WiFi AP can be expressed as

$$\mathcal{K}_{max} = \left\lfloor \frac{\mathcal{A}_C}{4\, r_1^2} \right\rfloor \tag{1}$$

Where [.] is the floor operator. We assume total mobile users (N_T) are distributed uniformly in cell coverage. The overall users under the WiFi coverage (N_W) are expressed as

$$N_W = k\eta N_T \tag{2}$$

Where η denotes the ratio of one AP area to the cell area ($\mathcal{A}_C$) and it can be expressed as

$$\eta = \pi\, r_1^2 / \mathcal{A}_C \tag{3}$$

where $\mathcal{A}_C = \frac{3\sqrt{3}}{2}\mathcal{R}_C^2$ and r_1 denotes the WiFi coverage range. The number of nodes in every WiFi AP area is $n = N_W/k = \eta N_T$ and the number of users which only be served by LTE is $N_C = (1 - k\eta)N_T$.

The throughput user in two modes of DCF and CoopMAC protocols are denoted as $\mathcal{S}_{user}^{DCF}$ and $\mathcal{S}_{user}^{Coop}$ and they can be expressed as

$$\mathcal{S}_{user}^{DCF/Coop}(k, \eta, N_T, E[P]) = \frac{\mathcal{S}_{AP}^{DCF/Coop}}{n} = \frac{\mathcal{S}_{AP}^{DCF/Coop}}{\eta N_T} \tag{4}$$

Where $\mathcal{S}_{AP}^{DCF}$ and $\mathcal{S}_{AP}^{Coop}$ denote the access point throughput of DCF and CoopMAC protocols respectively and they can be obtained according to numerical analysis in [15] and [14], and $E[P]$ denotes the average packet size. Moreover, the user cellular throughput can be expressed as

$$\mathcal{S}_{user}^{C} = \frac{\mathcal{S}^C}{N_C} = \frac{\mathcal{S}^C}{(1 - k\eta)N_T} \tag{5}$$

Where $\mathcal{S}^C$ denotes the cellular bandwidth of one eNB. To evaluate the offloaded traffic, we define a metric (β) for DCF and CoopMAC protocols as follows:

$$\beta^{DCF/Coop} = \frac{k\mathcal{S}_{AP}^{DCF/Coop}(k, \eta, N_T, E[P])}{\mathcal{S}^C} \tag{6}$$

The computation of β^{DCF} and β^{Coop} are summarized in Algorithm 1. In this algorithm, the impact of geometrical parameters (e.g. k and η), the number of users (N_T) and average packet size ($E[P]$) is investigated on the β value.

Algorithm 1: Algorithm of compute β^{DCF} and β^{Coop}

Initialize N_T, $E[P]$, K
for $i=1:N_T$ **do**
  for $k=1:K_{max}$ **do**
    for $t=1:E[P]$ **do**
      Compute $\beta^{DCF}(k, \eta, N_T, E[P])$
      Compute $\beta^{Coop}(k, \eta, N_T, E[P])$
    end for
  end for
end for

Now the main challenge is to investigate the impact of k number of WiFi APs on the β value. Moreover, it is very important for WiFi operators to deploy the minimum number of WiFi AP (k_{min}) for different average packet sizes and a different number of users when the specific value of β value should be achieved. Algorithm 2 summarizes the computation to achieve k_{min} for DCF ($k_{min\text{-}DCF}$) and CoopMAC ($k_{min\text{-}Coop}$) protocols. In this algorithm, the number of users, the packet size and a specific β (β_{thr}) are initialized. Then, the number of k is initiated by one and it is incremented by one while $f < \beta_{thr}$. The function f is computed similarly to β for each k (eq. 4). This algorithm will be applied to a different number of users and different packet sizes.

Algorithm 2: Algorithm of compute $K_{min\text{-}Coop}$ and $K_{min\text{-}DCF}$

Initialize N_T, $E[P]$, β_{thr}
for $b=1:Number(\beta)$ **do**
  for $i=1:N_T$ **do**
    $K=1$
    for $t=1:E[P]$ **do**
      Compute $f\left(\eta, K, N_T, \mathcal{S}_{AP}^{Coop}\left(or\ \mathcal{S}_{AP}^{DCF}\right), \mathcal{S}^{C}\right)$
      while $\left(f < \beta_{thr}\right)$
        $K=K+1$
        Compute $f\left(\eta, K, N_T, \mathcal{S}_{AP}^{Coop}\left(or\ \mathcal{S}_{AP}^{DCF}\right), \mathcal{S}^{C}\right)$
      end while
      $K_{min\text{-}Coop}(i, t, b)=K$
      $K=1$
    end for
  end for
end for

3- Numerical results

In this section, an offloading scenario is analyzed using DCF and CoopMAC protocols in MATLAB. The main objective of this evaluation is to investigate the spectrum efficiency provided by two MAC protocols and its impact on offloading efficiency. Moreover, their influence on the WiFi APs' deployment is also taken into consideration. This analysis is performed based on the IEEE 802.11n standard and Table I indicates its features in which d_i and r_i are data rates (in Mbps) and range (in meter) for BER= 10^{-5}. The cellular technology is LTE in which bandwidth and the cell radius are respectively 56.394 Mbps and 500 m. In order to apply different user density, the number of users is changed from 100 to 2000 in a cell. Due to the impact of the packet size on the performance of WiFi networks, different packet sizes are applied to the analysis: 512, 1024, 2048 bytes.

To evaluate the traffic offloaded, the value of β is computed for different numbers of APs. Since the pattern of β is similar for different values of k, only $k=1$ and $k_{max}=12$ (according to eq. (1)) are presented here. As indicated in Fig.2.a, by the deployment of one AP ($k=1$), the users in WiFi coverage with DCF protocol have 10% to 18% of traffic is offloaded by WiFi access technology when a total number of users and packet sizes are varied. In the same scenario with CoopMAC protocol, the offloaded traffic changes from 14% to 22% with one AP ($k=1$). The larger packet size, the less overhead in WiFi occurs and more value of β is achieved in both CDF and CoopMAC protocols. Moreover, due to the expected spectrum efficiency provided by cooperation schemes, the offloaded traffic by CoopMAC protocol has an improvement of 2% to 72% in comparison to the scenario with the DCF protocol. According to setting parameters, $\eta = 0.064$ and thus by adding one AP, 6.4% of users will be added to the WiFi coverage and maximum WiFi coverage will be 76.8% when maximum number of APs ($k_{max}=12$) are deployed. Fig. 2.b indicates the maximum offloaded traffic when the maximum number of APs ($k=12$) is deployed. With DCF protocol, it is possible to perform offloading 114% to 220% of LTE bandwidth while CoopMAC protocol is able to perform offloading in range the of 165% to 262% of LTE bandwidth. Similar to scenario with one AP, in this scenario CoopMAC protocol outperforms DCF protocol in offloading scenario. Moreover, the results of Fig. 2(a) and fig.2(b) present the lower bound and upper bound of offloaded traffic with various packet sizes and different user density.

To evaluate the impact of CoopMAC protocol on APs, deployment in the offloading scenario, the results of Algorithm 2 are indicated in Table II. The analysis is performed for different offloaded traffic (β=0.8, 1, 1.1), various packet sizes (512, 1024 and 2048 bytes) and a different number of users (100 to 2000). The pair of ($k_{min\text{-}Coop}$, $k_{min\text{-}DCF}$) denotes the minimum number of APs when CoopMAC and DCF protocols are used in the WiFi network respectively. As shown in Table II, in different situations we have $k_{min\text{-}DCF} \leq k_{min\text{-}Coop}$, meaning that CoopMAC protocol provides fewer APs when compared to DCF protocol. Although, there exists no special pattern for this reduction, the smaller the packet size, the more difference is between $k_{min\text{-}DCF}$ and $k_{min\text{-}Coop}$.

Table I. Data rates and corresponding ranges of IEEE 802.11 n

d_i (Mbps)	7.2	14.4	21.7	28.9	43.3	57.8	65	72.2
r_i (m)	115	91	78	62	46	34	31	29

Table II. ($k_{min\text{-}Coop}$, $k_{min\text{-}DCF}$) for different E[P] and β_{thr}

β_{thr}	0.8			1			1.1		
E[P] (Bytes) / N_T	512	1024	2048	512	1024	2048	512	1024	2048
100	(6,8)	(5,6)	(5,5)	(8,10)	(7,8)	(6,6)	(8,11)	(7,8)	(7,7)
500	(4,7)	(4,6)	(4,5)	(5,9)	(5,7)	(5,6)	(6,10)	(6,8)	(6,6)
1000	(5,8)	(4,6)	(4,5)	(6,9)	(5,7)	(5,6)	(6,10)	(6,8)	(6,7)
1300	(5,8)	(4,6)	(4,5)	(6,10)	(5,7)	(5,6)	(7,11)	(6,8)	(6,7)
1500	(5,8)	(4,6)	(4,5)	(6,10)	(5,8)	(5,6)	(7,11)	(6,8)	(6,7)
1700	(5,8)	(5,6)	(4,5)	(7,10)	(6,8)	(5,6)	(7,11)	(6,8)	(6,7)
2000	(6,9)	(5,6)	(4,5)	(7,11)	(6,8)	(5,6)	(8,12)	(6,9)	(6,7)

4. Conclusions

In this paper, the problem of APs' deployment in WiFi offloading has been investigated when a well-known cooperative MAC protocol in WiFi networks (CoopMAC) is exploited. The proposed system model consists of an LTE cell with several multi-rate APs inside. The overhearing and multi-rate feature permits to find the best relay node in the neighborhood of a source node and the AP. The selected relay node provides a two-hop transmission faster than a direct one. The spectrum efficiency provided by the CoopMAC protocol leads to perform more efficient offloading when it is compared to the DCF protocol. The analysis was performed for the IEEE 802.11n standard in DCF and CoopMAC protocol. One metric was proposed to measure the offloaded traffic as a coefficient of LTE bandwidth (β). This metric is computed for DCF and CoopMAC in a proposed algorithm. The second algorithm was also proposed to compute the minimum APs' required to provide an intended β value when associated parameters are various. The results of the second algorithm demonstrate that the CoopMAC protocol leads to employing fewer APs when it is compared to the DCF protocol. For future works, there exist several research lines. The energy efficiency of DCF and CoopMAC protocol and combination to spectrum efficiency can be the first issue which can be attractive for research. Moreover, solving the problem of APs' placement is important when the user density is not uniform and hybrid of cooperation and non-cooperation schemes can be the solution depending on the traffic under every AP coverage. Besides, the impact of CoopMAC protocol can be investigated when another connectivity scheme such as IFOM [16] is employed.

Abbreviations

AP: access points; LTE: Long Term Evolution; RSS: received signal strength; UE: user equipment.

Authors' contributions

Rasool Sadeghi is the main author of the study and carried out the theoretical and numerical works. Mehdi Hamidkhani contributed to the development of the ideas, result analysis, and article writing.

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Availability of data and materials

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

Competing interests

The authors declare that they have no competing interests.

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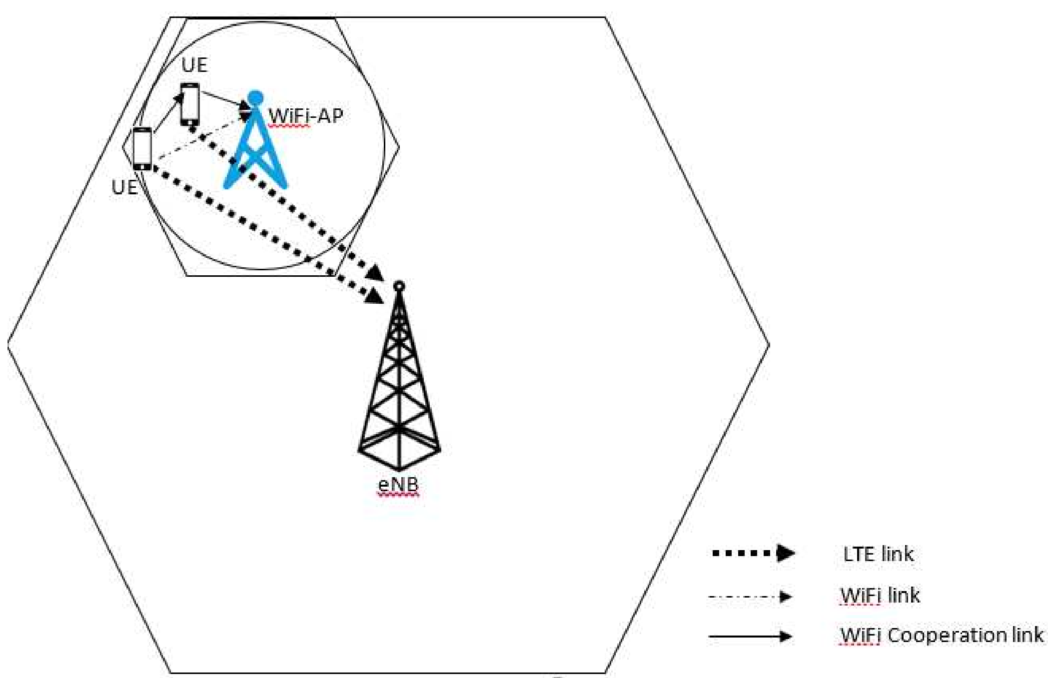
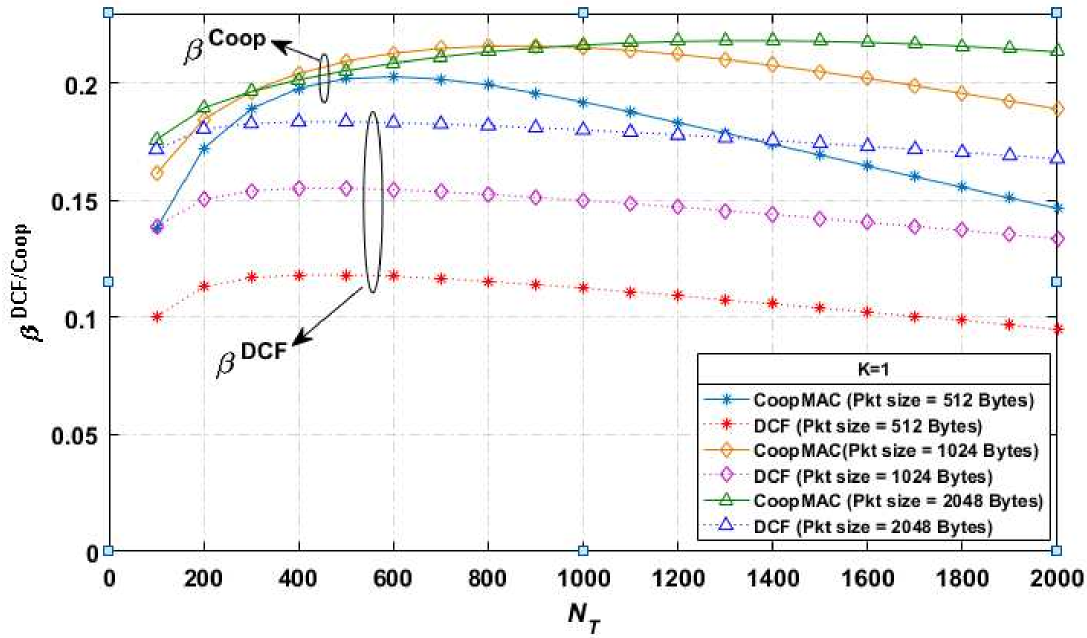
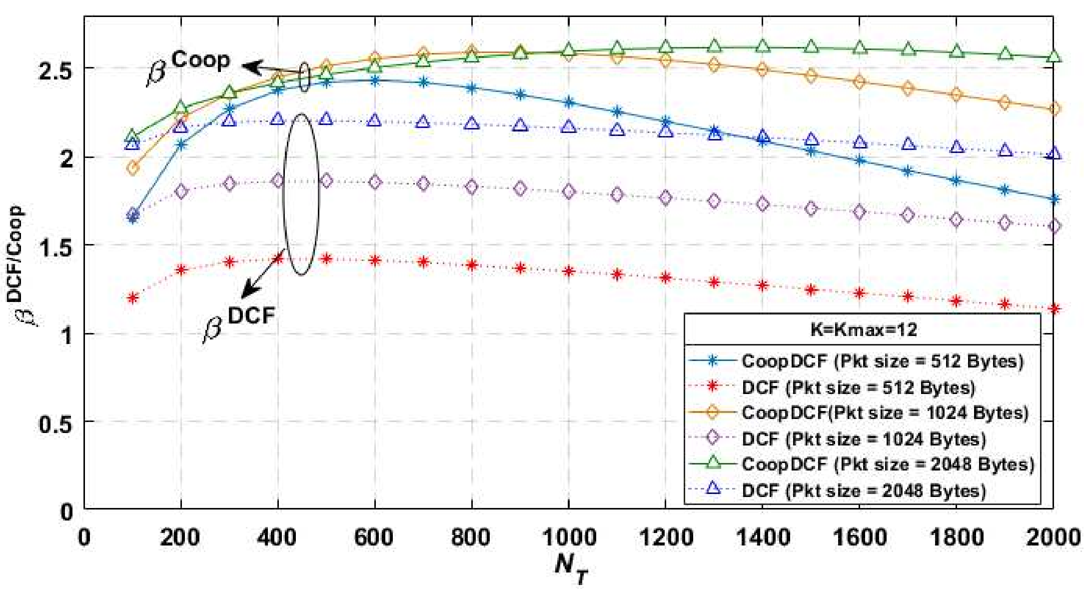


Fig. 1: Data offloading using cooperation and non-cooperation links.



(a)



(b)

Fig.2: $\beta^{DCF/Coop}$ a) one AP (k=1) and b) Maximum number of APs (k=kmax=12)

Figures

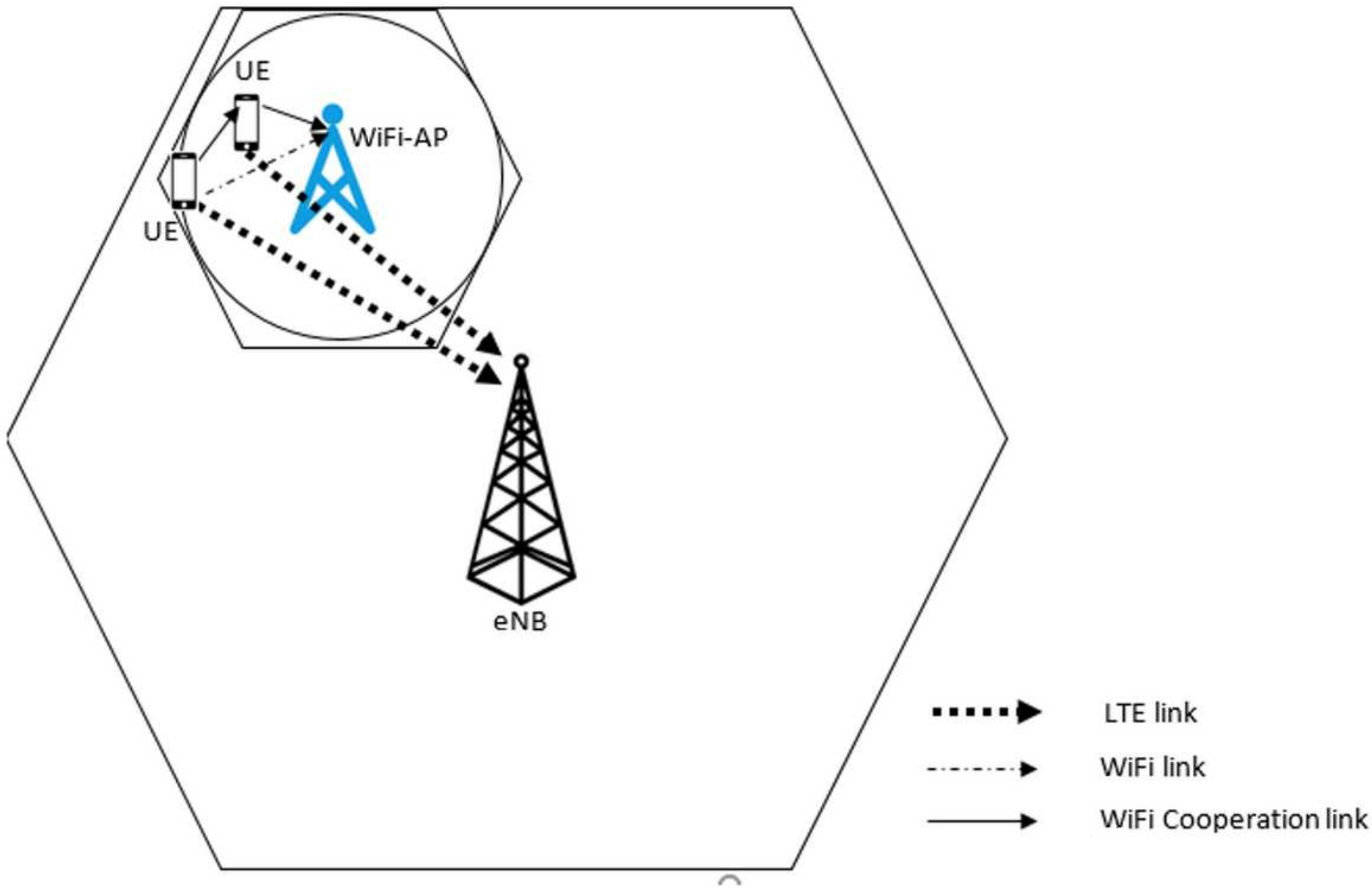


Figure 1

Data offloading using cooperation and non-cooperation links.

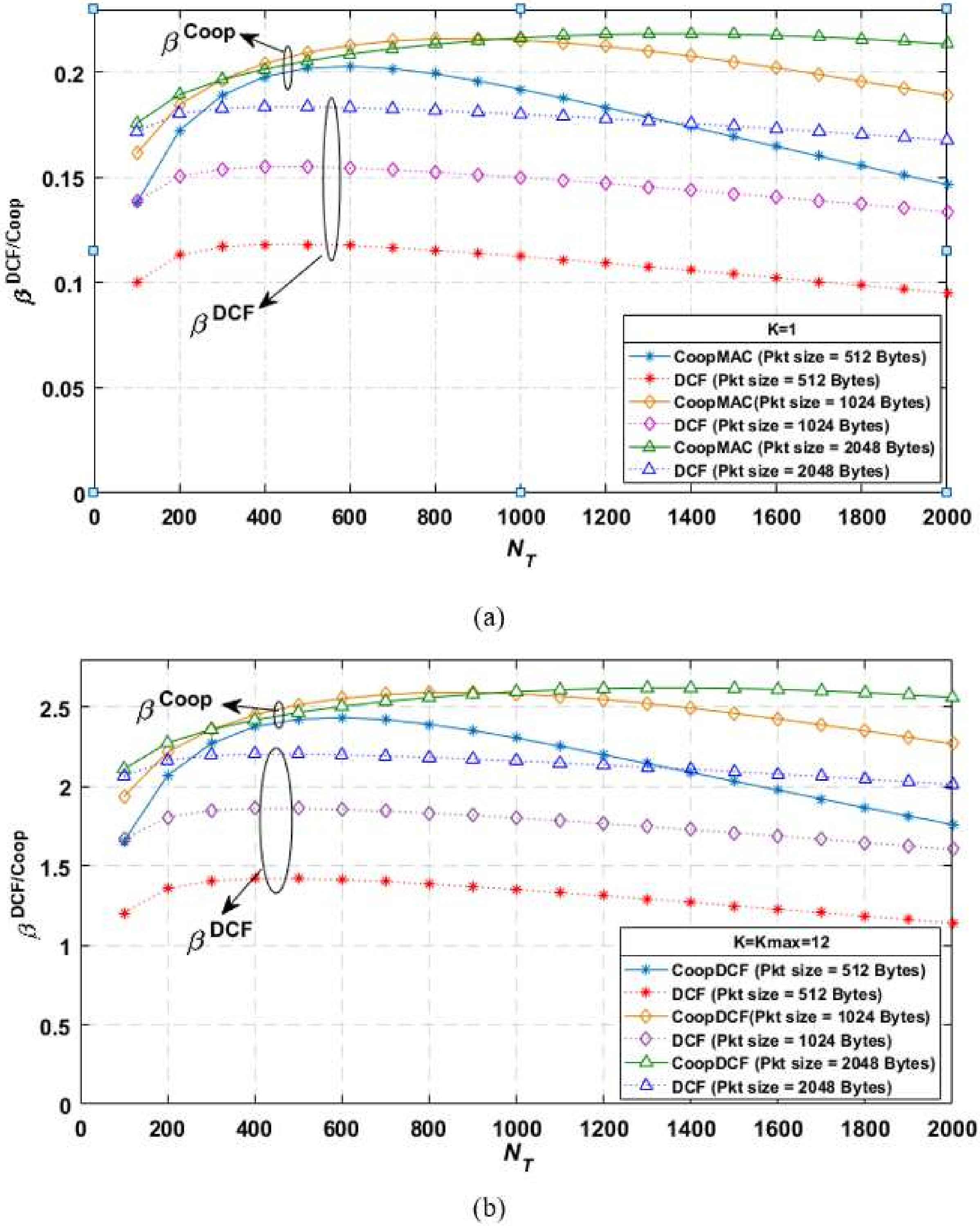


Figure 2

β^(DCF/Coop) a) one AP (k=1) and b) Maximum number of APs (k=kmax=12)