MFW: Mobile Femtocells utilizing WiFi

A Data Offloading Framework for Cellular Networks using Mobile Femtocells

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***Abstract*—The ever growing data traffic generated by users in cellular networks is becoming more challenging and straining for cellular operators. Thus, developing efficient mechanisms that enable cellular operators to offload data traffic from their networks in a cost-effective manner is essential. To this end, we propose a generic framework (MFW) that exploits femtocells and WiFi networks. The framework allows cellular operators to offload part of the traffic load generated by mobile users in public transportation systems, viz.; buses, streetcars. Regular Femto Base Stations (FBSs) are installed in these vehicles to offer cellular coverage for mobile devices, called the mobile FBS (mobFBS). The mobFBS utilizes ubiquitous WiFi access points as a backhaul to route the traffic to the cellular operator's network through WiFi instead of the loaded macrocells. Mobile data users are categorized in our framework in different prioritized classes in order to efficiently allocate the mobFBS bandwidth to the maximum number of users. Efficiency is considered in terms of bandwidth utilization, enhancing capacity and managing grouped data traffic in vehicles. We elaborate on the performance of MFW via numerical experiments, emulating practical applications, viz. "Skype" and "YouTube", and demonstrate the efficiency of our framework in terms of data traffic offloading.**

Keywords- mobile femtocells; WiFi; data offloading; mobile data traffic; macrocell offloading.

I. INTRODUCTION

Current cellular networks are experiencing an explosive growth in data traffic and they are practically overburdened. This growth has been driven by the proliferation of smart devices, data-hungry mobile apps (e.g., online social networks, video streaming), flat-rate data subscriptions, and data USB modems. According to Cisco's Global Visual Networking Index (VNI), since 2007, global mobile data traffic is doubling every year. It is predicted that this rate of growth will even increase more over the next few years [1]. Concurrently, the number of mobile subscribers has significantly increased in the last few years. Moreover, it is expected that the number of mobile devices will exceed the world's population by the end of 2012 [1].

To cope with this dramatic increase in mobile data traffic, cellular operators search for new solutions to enhance the capacity and offload traffic from loaded macrocell networks. To this end, several approaches have been proposed. The two most promising solutions for cellular operators are femtocells and the deployment of heterogeneous networks with Wireless Fidelity (WiFi) for dual-mode devices, i.e. cell phones with WiFi and cellular radio interfaces.

A femtocell is a cell in a cellular network that provides radio coverage and is served by a Femto Base Station (FBS). FBS is a miniature low-power BS typically installed by end users and deployed in indoor environments to provide better coverage, enhance data capacity and offload mobile traffic from macrocells [2][3]. Femtocells operate in the licensed spectrum, and have up to a hundred meters of coverage and can support up to ten active users in a residential setting [2]. FBSs connect to standard cell phones and similar devices through their radio interfaces such as Long Term Evolution (LTE) networks. Traffic is then routed to the cellular operator's network via a broadband connection (e.g. DSL, cable) [3]. Recently, many cellular operators have started rolling out outdoor FBSs in rural and densely populated areas [4] to enhance their coverage. However, femtocells prove useful in other scenarios, such as, in public transportation systems.

In this paper, we propose an efficient data offloading framework for cellular networks utilizing femtocells via WiFi networks; dubbed MFW. We propose to use the FBSs in public transportation systems, such as buses. We name such FBSs in vehicles as mobile FBS (mobFBS). Each mobFBS has a WiFi transmitter installed on the roof of the vehicle to utilize urban WiFi Access Points (APs), which are widely used and cover many urban cities [5], as backhauls. Mobile devices are connected to the onboard mobFBS instead of macro-BSs. Only mobile users with data sessions will be accommodated by the mobFBS. Nevertheless, we take into account the capacity of the mobFBS in terms of accommodated users and total available bandwidth.

We categorize mobile data users in different prioritized classes in order to efficiently allocate the mobFBS bandwidth to the maximum number of users. Then, mobile data traffic is routed to the cellular operator's network through WiFi; relieving the loaded macrocells. Macrocell offloading via MFW significantly improves overall cellular networks with notably less need for upgrading or modifying the network infrastructure. To the best of our knowledge, this is the first mention of an approach utilizing WiFi as a backhaul for mobile femtocells towards offloading mobile data traffic.

The remainder of this paper is organized as follows. We present the background and related work to this paper in Section II. Section III articulates the proposed framework and its components, in addition to an elaborative instance of the MFW framework. We present numerical results in Section IV, followed by our conclusions in Section V.

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II. BACKGROUND AND RELATED WORK

Our work builds upon mobile femtocells that have been proposed for deployment in vehicles, and on wide coverage WiFi networks. In this section, we elaborate on the mobile femtocell concept and related work, and wide coverage WiFi networks. We also discuss the motivations behind our proposed framework.

A. *WiFi – the larger scale*

Nowadays, WiFi networks are widely used by cellular operators to improve capacity and offload mobile traffic load for dual-mode phones [5]. Hence, many cellular operators began to build their own WiFi networks, such as AT&T and T-Mobile in the USA [5]. In addition, other carriers only offer WiFi coverage, such as Boingo® wireless. Thus, WiFi wide range deployments cover numerous cities over the world [5]. Different amendments have been introduced to the IEEE 802.11 WiFi standard to improve its performance and services. For example, IEEE 802.11r was implemented to provide continuous connectivity while cell phones are in motion, with fast and secure handovers. Also, IEEE 802.11e was proposed to support Quality of Service (QoS) in WiFi networks [6].

Thus, current WiFi standards support mobility, QoS and fast authentication [7][8]. It is worth mentioning that authors in [9] study the feasibility of using long range WiFi as a backhaul for fixed FBSs in rural areas. They show that the solution can reduce deployment and operational costs for cellular operators in rural environments. Yet, the proposed solution is only for voice communications. The survey presented in [6] stresses the utility of WiFi as a backhaul for BSs.

B. *Mobile Femtocells*

Mobile femtocells in vehicular environments (e.g., buses, streetcars) are primary introduced to offer better cellular coverage and capacity onboard. The mobile femtocells can be used to aggregate mobile traffic load and relay it to macrocells or to other access networks. Offloading this aggregated traffic in mobFBSs is essential. A limited number of contributions proposed deploying mobile femtocells. To enhance the service quality of mobile users in vehicular environments, the authors in [10] proposed deploying femtocells in vehicles to offer better coverage due to the short distance between the FBS and User Equipment (UE). The FBS is connected to the cellular operator's Core Network (CN) through the serving macro-BS or satellite communication. The authors in [11] present an architecture to provide Internet coverage in trains by installing femtocells. Onboard FBSs are connected to a heterogeneous gateway that consists of multiple wireless interfaces on the roof of the trains. The gateway is responsible for selecting the best wireless interface. While, the authors in [12] investigate benefits of using mobile femtocells in vehicles, specifically for the amount of signaling overhead incurred by mobile femtocells and macrocells.

C. *Mobile Femtocells utilizing WiFi (MFW) –Motivation*

Mobile femtocells that are directly connected with macro-BSs will not offload much data traffic; since only the control signaling overhead will be leveraged. However, the amount of voice and data traffic that goes through macro-BSs remains problematic. As most of the current macro-BSs backhaul bandwidth is limited, such a solution will not remedy the issues of mobile traffic. On the other hand, there are limitations for using WiFi with cellular networks as a single heterogeneous network, such as:

- The need for dual-mode devices, hence backward compatibility with heritage devices is infeasible.
- Mobile users would need to subscribe to two plans, one for the cellular network and another for the WiFi carrier, especially if not pushed by the cellular operator (as in the aforementioned AT&T example).
- Connecting through WiFi typically consumes more power than connecting to cellular networks; therefore, battery life becomes a major concern for mobile devices.
- Switching dual-mode devices between cellular and WiFi networks is currently not seamless.

Towards surmounting these limitations, we propose a generic framework for mobile traffic offloading that addresses the following aspects:

- Enhancing macrocell operation by offloading a portion of its traffic onto mobile femtocells.
- Eliminating the need to purchase new dual-mode devices.
- Extending battery life. UEs will receive stronger signals and improved Signal to Interference plus Noise Ratio (SINR) levels due to the shorter distance between the mobFBS and the UEs, which reduces power consumption.
- Enabling location-based services in transportation systems.

III. THE MOBILE FEMTOCELL FRAMEWORK – UTILIZING WIFI (MFW)

The Mobile Femtocells utilizing WiFi (MFW) framework enables cellular operators to offload a portion of data traffic from the overburdened macrocells to the mobFBSs installed in public transportation vehicles. The mobFBS offers cellular coverage, as any regular BS, as far as the UEs onboard. The mobFBS is connected to a power source and a WiFi transmitter that is installed on the roof of the vehicle. This WiFi transmitter provides the backhaul for the mobFBS by connecting to urban WiFi APs. As voice calls and idle users traffic do not consume much recourse from the macro-BSs, we mainly propose offloading only data traffic.

Spectrum allocation should be taken into consideration with MFW deployments. There are three scenarios for sharing the spectrum between macrocells and femtocells [13]. First, using dedicated spectrum, macrocells and femtocells work on different frequency bands. Second, is to share all available spectrum bands between macrocells and femtocells. Third, is partial co-channel models, where macrocells and femtocells share a portion of the spectrum and the rest is reserved for macrocells.

A. *Components*

MFW is composed of four entities: UEs, mobFBSs, macro-BSs, and WiFi transmitters.

- **UE:** could be any handheld device that has a cellular interface (such as cell phones, laptops, smart phones,

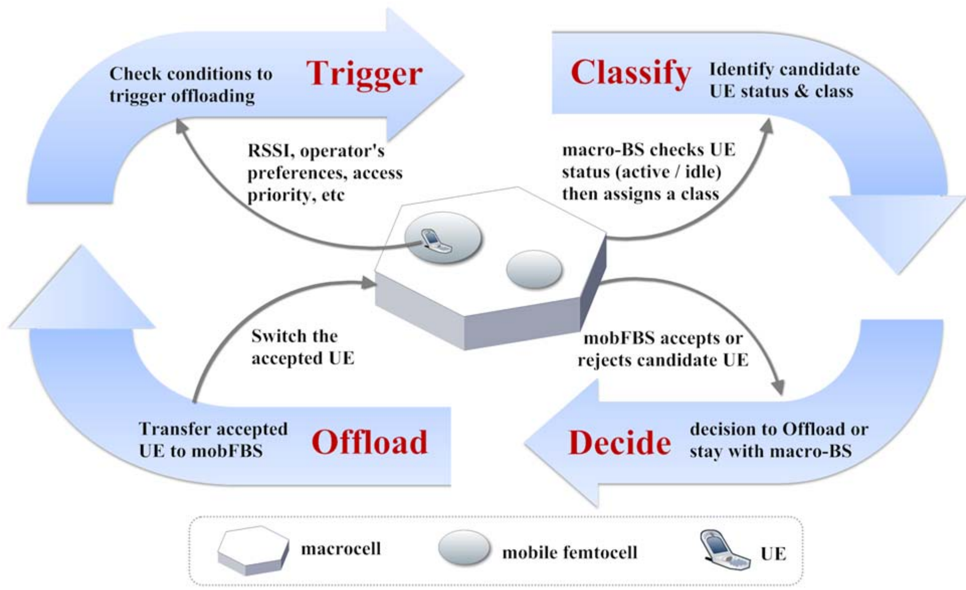

Figure 1. MFW core operational stages

tablets). We define a set of user equipment $U = \{UE_1, UE_2, .. UE_k\}$, where UE_i is the i^{th} user equipment in U.

- **mobFBS:** we consider an enterprise FBS that can simultaneously serve up to 60 users, and growing. It is registered and preconfigured in all ubiquitously accessible WiFi APs. A mobFBS has preemptive priority in accessing roadside WiFi APs. This is easily achievable since the linger time of vehicles with mobFBS, in any of these WiFi APs, is limited.
- **macro-BS:** a regular existing macro-BS.
- **WiFi transmitter:** a WiFi antenna is installed on the roof of the vehicle to connect with accessible WiFi APs. The WiFi transmitter is wired to the mobFBS via wires. WiFi APs are owned by cellular operators or WiFi carriers. In the latter, the cellular operator makes service agreement with the WiFi carrier.

B. MFW operational stages

Our offloading framework consists of four core stages, as shown in Figure 1: (1) Trigger stage, (2) Classify stage, (3) Decide stage and (4) Offload stage.

In the **Triggering stage**, once a UE_i enters the coverage of mobFBS; a trigger to offload will be initiated based on a predefined network condition (e.g. mobFBS's RSSI, operator's preferences, enforced handover). When the trigger condition is satisfied, the UE_i sends a request to be transferred to mobFBS.

In the **Classification stage**, the serving macro-BS receives the request of the UE_i then checks its status. The status of a UE is "**idle**" when it has neither a voice call nor a data session, and is "**active**" when it has either. If the status of UE_i is idle, it remains connected to the serving macro-BS. However, if its status is active, the macro-BS will then check if UE_i has a voice call or a data session. For a voice call, the UE_i remains connected to the macro-BS. Yet, if it has a data session, the macro-BS will classify the users' data request in different classes based on the applications priority [14]. In our framework, we define a number of user classes $C = \{C_0, C_1, \cdots, C_n\}$, where $\boldsymbol{C_n}$ has the highest priority in $\boldsymbol{C}$. For example, video streaming users will be given the highest class C_n, while HTTP users will be given the lowest priority C_0, and so on. Then, the macro-BS waits for a residence time and sends the user's request and its class type to the mobFBS. This residence time threshold is to verify that the UE is not a temporary visitor that resides outside the vehicle while it had stopped. The set of allocated bandwidth, ω_i is associated with each user C_i, the higher the $\boldsymbol{i}$ is the higher the bandwidth, i.e. $\omega_i < \omega_{i+1}$.

In the **Decision stage**, after the mobFBS receives a candidate user UE_i to offload, it chooses which eligible candidate user to offload from the macro-BS based on two conditions. First, the current number of user equipment, U_f, which are connected to a mobFBS should be less than the maximum number, U_{fmax}, a mobFBS can accommodate simultaneously. Second, the total bandwidth currently used, T_{total}, in addition to the requested bandwidth, ω_i, should be less or equal to the available bandwidth of the mobFBS, $\boldsymbol{\gamma}$**.** Once these conditions are met, the mobFBS will accept the candidate user (UE_i), then, increase the U_f and inform the macro-BS. Otherwise, the UE_i will be rejected. However, if a specific number of rejections to a given class are made, it becomes a higher priority class in order to efficiently assign the mobFBS bandwidth to the maximum number of different user classes.

Lastly, in the **Offloading stage**, the macro-BS will transfer the accepted candidate UE_i to the mobFBS and update the network. There are some cases where WiFi coverage is not available or the signal strength degrades below a certain threshold. If this happens, the mobFBS will ask the macro-BS to transfer the set of users associated with it.

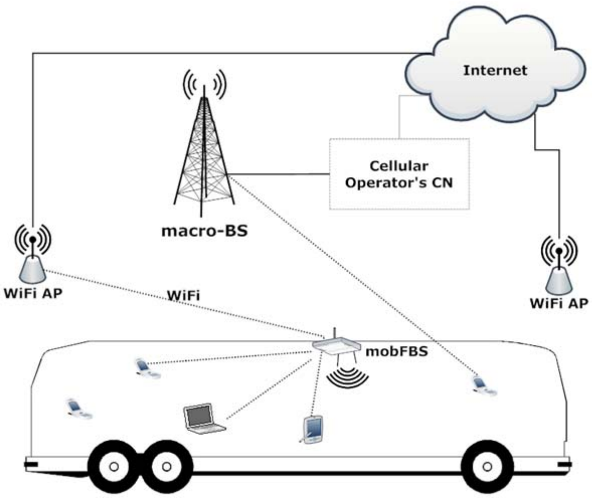

Figure 2. MFW instance

C. MFW Instance

We consider an instance of MFW consisting of the following: single macro-BS and mobFBS, multiple UEs and APs, as shown in Figure 2. The bus moves in an urban city, where vehicle speed limits are less than 60 km/h. MobFBS' Received Signal Strength Indicators (RSSI) is the **Triggering condition**. As in any cellular network, UEs should communicate with the BS that has the highest RSSI. Therefore, when a UE_i enters the bus, it will sense the mobFBS's high RSSI, due to the short distance between UE and the mobFBS. Then, the UE_i will report the mobFBS's RSSI to the serving macro-BS and send a Req_i.

Algorithm 1 represents the **Classification stage** at the macro-BS. When the trigger condition is satisfied, the serving macro-BS checks the status of the UE indicated in lines 2-5. If UE's status is active with data session, the macro-BS will classify the UE_i traffic as indicated in line 6. As a result, C_i will be associated with UE_i. The macro-BS waits a predefined residence time (*res_time*) and then sends the $DReq_i$ with its associated C_i to the mobFBS as in lines 7 and 8. However, if UE_i status is other than active with data, the macro-BS ignores UE's request and keeps it. After receiving the decision from the mobFBS, the macro-BS will switch (**Offloading stage**) the UE_i to the mobFBS if it receives an *Accept* message (lines 8 and 9). Otherwise, it will ignore the *UE's* request. The overall complexity of Algorithm 1is *O(n)*.

Algorithm 1: UE_i Classification at macro-BS

Input: Req_i**:** a request by UE_i to switch to mobFBS
1. Receive a Req_i from a UE_i
2. **If** UE_i is active **then**
3.   **If** the UE_i has a voice call **then**
4.   Ignore // i.e. keep connected to the macro-BS
5.   **Else**
6. C_i = Classify UE_i based on application types
7.   wait for *res_time*
8.   **If** (**Decide** (Req_i) = = Accept) **then**
9.   Transfer UE_i to the mobFBS
10.   **Else**
11.   Ignore
12.   **Endif**
13.   **Endif**
14. **Else**
15. Ignore
16. **Endif**
17. **End**

Algorithm 2: Decision at mobFBS

Decide ($DReq_i$)

Input: $DReq_i$: is a data user request from a UE_i associated with its C_i
Output: Accept/Reject: message sent to macro-BS to transfer/keep a UE_i
Initialize: U_f , U_{fmax} , T_{total} , UE_{min}
1. Receive a $DReq_i$ from macro-BS of UE_i
2. **If** $U_f < U_{fmax}$ AND $T_{total} + \omega_i \leq \gamma$ **then**
3.   Accept UE_i
4. $U_f = U_f + 1$
5. $T_{total} = T_{total} + \omega_i$
6. **Elseif** $U_f = U_{fmax}$ AND $\exists\, C_{i-1} \in U_f$ **then**
7.   Switch UE_{min} to macro-BS & Accept UE_i
8. $U_f = U_f + 1$
9. $T_{total} = T_{total} + \omega_i - \omega_{min}$
10.   **Else**
11.   Reject UE_i
12.   **Endif**
13. **Endif**
14. **If** degradation **then**
15. Trigger to transfer $\{U_f\}$ to the macro-BS
16. **Endif**
17. **End**

The mobFBS will decide to accept or reject UE_i based on the **Decide** function detailed in Algorithm 2. Once mobFBS receives the $DReq_i$ of UE_i, it will check to decide if it will accommodate it or not (lines 2-12), in the **Decision stage**. If the mobFBS chooses to accommodate UE_i, it will inform the serving macro-BS to transfer the data session of UE_i , update U_f and $T_{total,}$ (lines 3-4). However, if the mobFBS reaches its U_{fmax} and a UE_i is connected with mobFBS and has lower class priority than the entering UE_j. In this case, the mobFBS will transfer the UE_{min} to the macro-BS and accept UE_j (lines 6-9). Finally, if the WiFi signal strength degrades below a certain threshold, the mobFBS will ask the macro-BS to transfer its set of UE (lines 4 and 5). The overall complexity of Algorithm 2 is *O(n)*.

IV. NUMERICAL RESULTS AND DISCUSSION

In this section, we present numerical results of average data offloaded from the macro-BS to the mobFBS. We also verify the efficiency of the proposed MFW instance (explained in Section III.C) using real world numerical examples. That is, each macro-BS and mobFBS (γ) capacity is set to 30 and 5 Mbit/s, respectively. The U_{fmax} is 40 users. We assume three classes of data users, C_0 is HTTP traffic, C_1 is VoIP traffic and C_2 is video traffic. The minimum bandwidth required for each

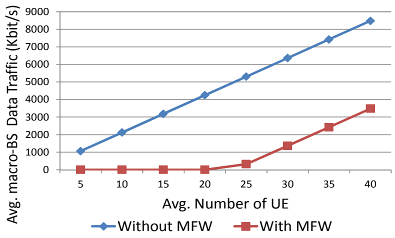

Figure 3. Avg. macro-BS data traffic vs. total number of UE

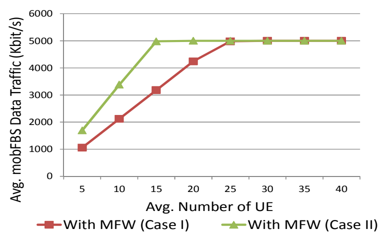

Figure 4. Avg. mobFBS data traffic vs. total number of UE under the two different cases

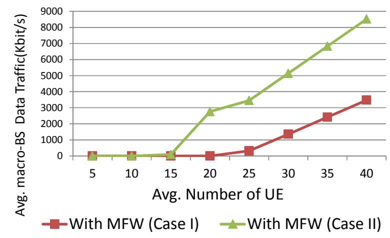

Figure 5. Avg. macro-BS data traffic vs. total number of UE under the two different cases

class, based on Skype and YouTube recommendations are as follows: ω_0 is 80 Kbit/s, ω_1 is 100 Kbit/s and ω_2 is 500 Kbit/s.

To elicit the efficiency of MFW on different classes, we assume two different cases. In case I (light traffic users), the percentage of UE asking for the three classes C_0, C_1 and C_2 are 40%, 30% and 30%, respectively. However, in case II (heavy traffic users), the percentage of UE asking for the three classes C_0, C_1 and C_2 are 10%, 30% and 60%, respectively. For this instance, we assume a number of UEs varying from 5 to 40. Numerical results determine the average offloaded data traffic from the macro-BS to the mobFBS at a given time period. The average offloaded data traffic load is considered as a function of total number of UEs.

In Figure 3, we demonstrate the efficiency of MFW in offloading data traffic from the macro-BS. It shows the macro-BS data traffic generated by UEs in the bus, before and after applying the MFW framework. MFW offloads up to 50% of the macro-BS data traffic when the maximum mobFBS bandwidth is achieved. We remark that the linear behavior of the plotted curves is due to the fixed assigned bandwidth for each UE.

Figure 4 shows the data traffic that has been offloaded via mobFBS given the two cases of data traffic distribution. It indicates a faster mobFBS capacity saturation given the heavy video traffic demand in case II. This means a faster offloading gain at macro-BS side.

The demand for video traffic increases offloading efficiency as depicted in Fig. 5. However, this might not be the average realistic demand, where the majority of UEs in public transportation will have lower video traffic demands. It is worth mentioning that offloading the same traffic with higher number of UEs is more beneficial for macro-BS, due to signaling overhead and power dissipation over a higher number of UEs. Moreover, we note that macro-BS data traffic gradually increases as video traffic increases.

V. CONLCLUSION

Femtocells and WiFi networks are seen as promising solutions to enhancing coverage and capacity, and offloading traffic in currently overburdened cellular networks. In this paper, we propose a data offloading framework for cellular operators by utilizing mobile femtocells and WiFi. Our proposed framework utilizes urban WiFi APs to be used as backhauls for mobFBSs installed in public transportation vehicles. Numerical results demonstrate the efficiency of MFW; mainly in terms of data traffic offloading. MFW can offload up to 50% of macro-BS data traffic when the mobFBS bandwidth is saturated.

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