An Integrated Data Offloading Approach for Mobile Users in Urban Environments

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Abstract— Rapid continual growth in the number of people who own mobile devices and rising demand for multi-media content increase the pressure on deployed wireless networks in general and on cellular networks in particular to support high quality of service. Service providers adopt various strategies such as imposing data-caps on users in a bid to reduce loads on their networks. End-user driven data offloading has the potential to reduce loads on service providers networks, increase the end-users overall data transfer rates and to reduce energy consumption by the mobile device due to networking operations. However, in the context of mobile users, efficient network detection and establishment of useful connections to WiFi networks is complicated by the speed at which users are travelling and the severely limited, practical range of the network coverage areas. In this paper we propose an integrated mobile device-centric approach to the problem of data offloading to WiFi networks that focuses on when a mobile user device should scan for alternative wireless networks and conditions under which they should connect to a detected network.

Keywords-WiFi; data offloading; mobile users; network scanning;

I. INTRODUCTION

Radio spectrum is a finite resource, but the demands placed on it are growing at an incredible rate. Mobile devices with multiple wireless adapters enable users to be always “best” connected and powerful processors coupled with high definition screens enable multimedia content to be consumed almost anywhere, at any time.

In many urban centres mass transport systems are actively promoted. They provide affordable, reliable transport but also result in large numbers of people arriving at a location simultaneously. Dense concentrations of subscribers in urban areas place a huge strain on communication networks. New technologies such as LTE and LTE-Advanced cannot keep pace with demand, as the speed and capacity of networks increase so does the consumer’s demand for multimedia content and bandwidth intensive services.

Building out new networks to meet demand is not a viable long term solution. Licensed spectrum is scarce and expensive and many urban centres are already saturated with cellular networks. New sites are increasingly difficult to find and expensive to acquire and as more and more radios are deployed in an area interference levels increase. In addition, any increased capacity may only be required for relatively short periods of time each day.

Solutions which network operators employ to reduce the effect of load on their networks are performing network-centric data offloading [1, 2], making use of load-balancing [3] and imposing data-caps on user traffic. In order to cope with the latter, the mobile users seek to reduce the amount of data transferred over cellular networks to avoid breaching their data-caps and incurring additional charges. A common solution is user mobile-device-centric data offloading to WiFi access networks. However, user device-centric data offloading to WiFi networks faces several challenges:

- Severely limited range of WiFi Access Points (AP)
- Bottlenecks arising from the limited capacity of sections of the wired back-haul from APs to the core network
- Mobile user travelling speed
- Network scanning delays
- Connection delays

A combination of limited range of WiFi APs and mobile user travelling speed can have a significant, negative impact on the data transfer rates for mobile users and consequently on Quality of Service (QoS) levels. The problem addressed in this research is one of how to facilitate user device-centric data-offloading to WiFi in such a way as to increase data transfer, reduce energy consumption and reduce the load on the cellular networks.

This paper proposes a mobile device-centric approach to data offloading to WiFi networks that focuses on when a mobile user device should scan for alternative wireless networks and conditions under which they should connect to one of these networks. This approach takes advantage of the delay tolerant nature of many popular types of mobile applications such as those based on video content. This delay tolerance is combined with the start/stop nature of mobile user journeys (including vehicular) in urban areas.

The proposed approach requires an integrated architecture consisting of IEEE 802.11 APs deployed at very specific locations and TV whitespace (TVWS) backhauls to act as links between the edge APs and the core network. The focus is on high populated urban centres, where the demand for wireless spectrum is the greatest, it is assumed that 3G/LTE coverage is widely available and that the cellular service provides impose the usual data-caps on subscribers.

The specific contributions of this paper are as follows:

- The proposed integrated solution that combines software and infrastructure to exploit the delay tolerant nature of various types of data and the start/stop/ nature of the urban transit systems
- The most effective positions in which to deploy APs in the context of mass transit users are identified
- A set of mobile user profiles and a connectivity policy based on the rate of speed of the mobile user to trigger handoffs between WiFi and cellular networks are constructed.

II. Related Works

Mobile device ownership is expected to continue to grow for the foreseeable future as for instance according to one report 84% of the world's population will be using a mobile device by 2018 [4]. Cisco [5] reports that by 2018 75% of all Internet traffic will be video, up from 57% in 2013. This puts additional pressure on the current infrastructure to deliver the services at high level of quality.

The operators of mobile phone networks are deploying LTE and LTE Advanced networks [6] to provide increased network capacity and data transfer rates, however the increased capacity is quickly consumed by users. In an effort to reduce the strain on cellular networks service providers offload traffic to alternative networks such as WiFi whenever the opportunity presents itself [7][8].

Mobile phone operators also deploy femto cells [9] to offload traffic from their networks and improve performance in buildings or other areas in which signal strength may not be good enough to provide an acceptable level of service. The femto cells act as bridges between the mobile device and the customers own broadband connection, this strategy forces the customer to supply their own backhaul and also provide energy to power the femto cell.

In both the case of data offloading and femto cell deployment the backhaul can quickly become a bottleneck. In most instances the customer's broadband connection being employed as the backhaul is an asymmetrical connection with the greater portion of the links capacity being devoted to the downlink and a much smaller portion of the link being devoted to the uplink. Although in most cases download traffic is vastly greater that upload traffic under normal circumstances, the combined uploads of many additional users may swamp the link.

The problem of lack of capacity on broadband connections used as backhauls was addressed in [10]. The authors propose aggregated backhauls consisting of multiple individual broadband connections and flexible, intelligent redirection of traffic between participating access points.

A move away from analog television to digital television services has made available large portions of radio spectrum that is well suited for use in data networks [11]. The exact frequencies being made available vary between regulatory areas, however the newly available spectrum has excellent propagation characteristics and range and also provide improved non-line of sight (NLOS) services due to their ability to penetrate masonry, foliage, etc. [12]

While some studies have shown that the newly available spectrum might not be capable of providing all of the benefits heralded by some of its early champions [13], field trials demonstrate that it can be an effective backhaul technology. Successful trial deployments have been completed at various UK locations [14] and the feasibility of using television white space (TVWS) for backhauls has been proven.

As the population of urban centers grows the traffic congestion on the streets becomes an ever greater problem leading to gridlock and greatly increased journey times [15]. Many local authorities are actively encouraging the use of public transport in a bid to reduce congestion and frequently, public transport gets priority in city centers [16] enabling the vehicles to travel faster than cars.

From a wireless communications point of view increases in the use of public transport present certain difficulties especially where data offloading to WiFi networks occurs. The problems arise from having a large number of users arriving within range of a access point simultaneously and the speed at which they are traveling.

Previous work [17] clearly demonstrate that the faster a mobile user is traveling the less time they have to establish a connection to the AP before they move out of range again. If a mobile user travelling at any speed discovers an AP the unavoidable connection delays associated with wireless communications further reduces the amount of time available to establish a connection. WiFi APs also have very short effective ranges which may result in frequent handoffs between cells for mobile users.

Much of the data transferred to and from mobile devices, e.g. video or email, is delay tolerant and can be transmitted in bursts when conditions permit without any loss of functionality [18].

III. Proposed Solution

To help address the problem of rapidly growing demand for wireless services within urban areas, this paper proposes an integrated solution that employs IEEE 802.11 APs to provide endpoint connectivity for mobile users, TVWS point-to-multipoint or TVWS point-to-point links for the backhauls with a network scanning strategy and an innovative connectivity policy for end-users. Although many network detection and selection strategies exist we believe that our approach is the most suitable in the circumstances since takes into consideration when it is most appropriate for a mobile user to scan for available wireless networks. A mobile user travelling at speeds greater that a fast walk has little chance of establishing a useful connection to a WiFi network in an urban environment and in the interest of data transfer rates, network efficiency and energy saving will not be allowed to do so.

Design Drivers

The design decisions for the proposed system are based on the results of a real world wireless survey and a series of simulations conducted using Network Simulator 3 (NS3) [19].

In modern, heterogeneous multi-network wireless environments the opportunity exists for the owner of a mobile device equipped with multiple wireless technologies to be always best connected. However, in order for such a user to be able to select a network for use the available networks must first be detected. The first phase of network discovery and selection begins with a mobile device scanning for wireless networks within range. This scanning process has been identified as a significant consumer of energy and various strategies have been proposed to reduce the amount of energy consumed [20]. Scanning for available wireless networks has also been identified as a key component in the delay experienced in establishing a connection to a wireless network. A scanning delay of 3.6 seconds is relatively common. The area of network detection and selection has been the focus of a great deal of research effort [21, 22]. However there are situations when it would ***not*** be in a mobile user's best interests to scan for and attempt to connect to WiFi networks. Eliminating unnecessary scanning operations would reduce energy consumption [23, 24]. Additionally, reducing the number of short lived connections to WiFi networks during which no significant amounts of data were transferred would also improve performance by not requiring a high number of handoffs between networks. In order to develop a realistic understanding of real world WiFi conditions we conducted a wireless survey in Dublin city center. The survey revealed that although a large number of APs were deployed throughout the survey area the actual coverage area of each detected AP was surprisingly small; on average coverage areas for 802.11n AP were roughly 28m in diameter, far less the oft touted theoretical maximum range of 300m. We believe that the severely restricted ranges in this instance arise from the nature of the survey areas built environment. Buildings in this area are solidly constructed from stone, brick, etc. and APs are deployed to serve the needs of the buildings inhabitants and not passersby.

We also tested the time taken to establish a connection to a detected AP and the average connection time was found to be approximately 4 seconds. This did not take into consideration the time required to establish a connection to a server and begin downloading files or the connection delay mentioned previously. In our tests we investigated both cellular and WiFi networks and observed that when reestablishing a data connection to a cellular network a seven second connection delay was experienced.

WiFi Connection Test Times (Seconds)					
Location	Distance from AP	Test 1	Test 2	Test 3	Test 4
Home Network	17 m	5.0	4.7	4.25	5.03
Home Network	2 m	5.33	4.7	3.39	5.06
Bus On-board AP	unknown	3.57	3.72	3.49	3.85

Table 1 WiFi Connection Delay

Connection Delays to 3G Network [secs]					
Inside	7.69	7.28	7.13	6.91	7.11
Outside	7.48	7.28	10.6	7.1	7.35

Table 2 3G Data Connection Delay

In order for a network connection to be of any benefit to an end user, it must persist for some period of time that enables the user to do something useful. It is impossible to predict what a user might consider to be a useful task in the context of the large variety of mobile applications. However for the purpose of this paper downloading and opening a webpage was considered the task of interest. The amount of time a mobile user remains in range of an AP depends on the coverage area of the AP and the speed at which the mobile user is travelling. The period of time required to carry-out useful tasks will be greater than:

$$CA/US - (sd + nad + cd)$$

where *CA* is the AP coverage area in metres, *US* is user speed in metres per second, *sd* is the scanning delay, *nad* is the time taken to establish a connection to an AP and *cd* is the amount of time required to open a web page in a browser.

Out tests involving a Nexus 7 tablet and a HTC Desire 380 phone have shown that the WiFi average scanning delay is 3.6 seconds and the average connection delay is 4.6 seconds. The time taken to load a web page in a browser obviously depends on the content of the web page itself. In our tests the Google search page loaded in 2.5 seconds and the Gmail's login page loaded in 3.3 seconds. Based on these values we will employ the shorter load time of 2.5 seconds. We calculate the **time required for useful connection to AP to be 10.7 seconds (3.6s + 4.6s + 2.5s)**

The restricted AP coverage area and connection delay present difficulties for passengers in vehicles and for users of public transport wishing to connect to available WiFi APs. Although many public transport services provide onboard WiFi access, the service is extremely limited using as it does a cellular connection that might need to be shared by up to 50 passengers at a time. It would make sense, from the end users point of view, to connect to external APs whenever the opportunity presents itself.

The current speed limit in Dublin city center is 30kmh or 8.33 m/s and traveling at this speed a mobile user would remain in the average observed coverage area of an AP (28m) for 3.36s, a period of time that does not even match the connection delay. Even if we were very generous and extended the AP coverage area to 150m or half the theoretical max we would have a dwell time of 18 seconds for a mobile node travelling at the speed limit. When the connection delays are considered, the duration in which useful works can be done is reduced to 7.3 seconds.

Short periods of connectivity such as this result in multiple breaks in connectivity and multiple unsuccessful scanning operations over a period of time.

Access Point Deployment

Our design positions the WiFi APs at those locations where mass transit commuters are most often stop i.e. the traffic lights at junctions and pedestrian crossings. The stop periods at the pedestrian crossings are set to increase in the coming years due to an aging urban population. Older pedestrians require a longer time to safely cross the road leading to greater stop periods. The longer stop periods provide an opportunity to mobile users to transfer large amounts of data.

Locating the WiFi APs at traffic lights has many advantages including access to multiple prime locations along known commuter routes which deliver large volumes of clients. The traffic lights provide ready access to power supplies and also provide AP mounting points at a useful height. Traffic light positions are known and unchanging and this predictability coupled with fixed bus routes means that bus arrival times can be predicted with some accuracy using positional updates from the buses.

Network Detection and Selection

Results from simulations conducted using NS-3 and based on the results of our wireless survey showed that for mobile users traveling in excess of the average urban pedestrian speed [25] the best strategy was to not attempt to scan for WiFi networks until they had reduced their speed or had come to a halt. By only scanning for and connecting to WiFi APs when conditions are suitable and the possibility of making a useful connection exists mobile users both conserve energy and increase their data transfer rates. In order to achieve this outcome we propose the use of the SONS [26] framework in conjunction with our proposed infrastructure. SONS abstracts from the user the decision of when to invoke a network detection algorithm with its associated scanning operations and when not to. SONS will only invoke a network detection and selection algorithm if the mobile node is stopped or travelling at speeds less than 4 metres per second. This strategy ensures that attempts to establish WiFi connections will only take place when the dwell time is long enough to get some useful work done.

Since the SONS framework only invokes the users preferred network detection and selection algorithm when the conditions for establishing a useful connection exist it reduces the overall number of wireless scans carried out. Reducing the number of unnecessary scans has two main benefits. Table 3 presents the total amount of data received by a mobile node travelling at various speeds during simulations with and without the SONS frame work. At the lower speeds there is no difference in performance but as the nodes speed increases the overall data transfer rates increase.

Total Amount of Data Received at the Mobile Node			
Node Speed (mps)	Data RX No-SONS (MB)	Data RX SONS (MB)	SONS Difference (%)
1.4	108.51	108.51	0
2	99.99	99.99	0
3	122.05	122.05	0
3.7	122.54	122.54	0
4	99.65	99.65	0
5	100.31	105.87	+5.5%
6	104.39	105.31	+0.88%
7	99.29	105.44	+5.83%
8	99.59	105.47	+5.58%
9	62.36	105.47	+40.87%

Table 3 Total amount of data expressed in megabytes received at the mobile node

Energy Consumption per WiFi Scan (mWatts)					
Node Speed (mps)	No. Scans No-SONS	Scan Energy 150mW per scan	No. Scans SONS	Scan Energy 150mW per scan	Energy Saving (mW)
1.4	7	1050	7	1050	0
2	12	1800	12	1800	0
3	16	2400	16	2400	0
3.7	18	2700	18	2700	0
4	18	2700	18	2700	0
5	20	3000	2	300	2700
6	20	3000	2	300	2700
7	21	3150	2	300	2850
8	21	3150	2	300	2850
9	24	3600	2	300	3300

Table 4 Estimated energy consumption due to WiFi scanning operations

Since every scanning operation whether successful or not consumes some amount of energy reducing the total number of scans also reduces the energy consumption by the mobile node.

Service Classes

User service requirements may be divided into two broad categories, delay tolerant services and delay intolerant services. Delay tolerant services include email and file transfer while delay intolerant services include voice and video traffic. With multi-homed devices that are equipped with network interfaces for both WiFi and cellular connectivity delay intolerant traffic can be sent over a cellular connection as and when required without the need to wait for a WiFi connection to become available.

The class of service required by the end user can be employed to determine whether or not to maintain a link to a cellular network. An end user seeks to conserve energy to prolong device usage and to transmit/receive the maximum amount of data possible during some period of time. In many cases these aims can be achieved by connecting to a WiFi network and breaking the connection to a cellular network. This strategy is appropriate when the data to be sent/received is delay tolerant. However, in the case where data transmission cannot tolerate delays (e.g. voice communications)it may be more appropriate to ignore energy consumption and lower data transfer rates and to remain connected to a cellular network that has greater coverage that a WiFi network. Offloading delay tolerant data to WiFi networks has the effect of reducing the overall load on cellular networks thereby helping to provide additional capacity for those users who remain on the cellular network thus giving them a better QoS.

Figure 3 illustrates the basic network architecture and the connectivity choices made by a mobile user based on their service class requirements. At position A the mobile user can connect to a cellular network, at position B they can opt to connect to WiFi only and at position C they can connect to both.

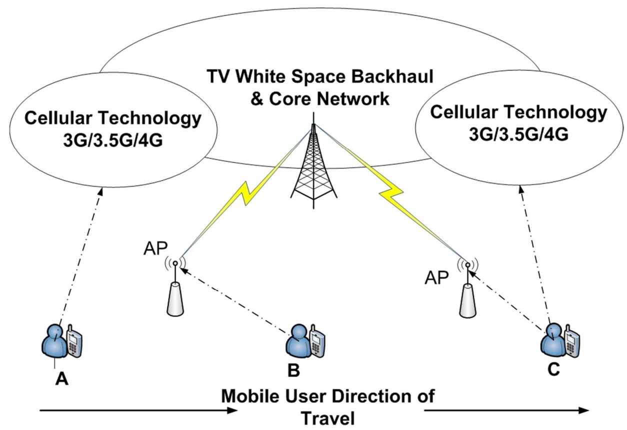

Figure 3 Mobile user connection choices based on Service Class

Connection Policy for Mobile Users in Urban HetNets

The aim of the policy is to promote efficient data transfer for mobile users through the exploitation of user mobility patterns. The results of the simulations described previously clearly demonstrated the benefits of searching for and connecting to short range WIFI APs when a mobile user was stopped or moving at a suitably low speed to enable a useful connection to be established.

Our connectivity policy is based on user mobility profiles as shown in Figure 4. Depending on the profile that the user matches, WiFi connection attempts may be permitted or blocked. A mobile user who is currently stopped will always be permitted to search for and connect to available WiFi networks. This is also the policy applied to mobile users travelling at average urban pedestrian speeds. A mobile user who is slowing down or gradually increasing speed from a stopped position may be permitted to search for and connect to available networks depending on their speed. Mobile users who are travelling at rates in excess of pedestrian speeds should not be permitted to connect to available WiFi networks.

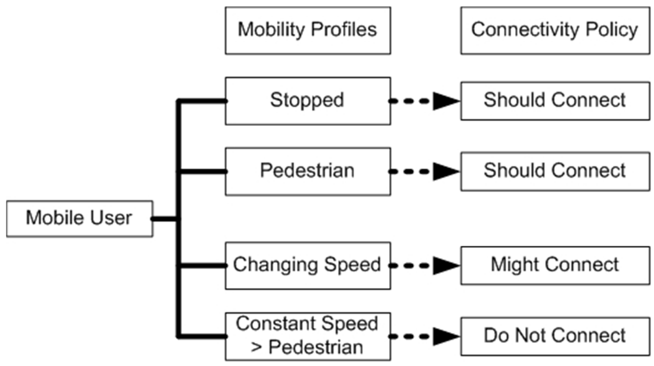

Figure 4. Mobility Profiles and Connectivity Policy

However, it is envisaged that users would always have the ability to override any action taken on their behalf by the Connection Policy and Scanning Policy. The fact that a mobile node is travelling at a speed that, on the face of it, makes it unlikely that a successful connection to a wireless network could be made should not be sufficient to disable network selection. In certain circumstances it is possible that a mobile node could travel at a relatively high rate of speed and still need to engage in network selection. For example, many public transport systems provide free on-board WiFi for passengers. In this case the mobile user is potentially travelling at a high speed yet remains within the relatively narrow coverage area of the on-board wireless AP and therefore network selection should be enabled.

IV. CONCLUSION

Growing demands for multi-media content delivered to mobile devices places ever greater pressure on finite spectrum resources. Our proposed integrated system strategically deploys WiFi APs in urban areas such that they take advantage of commuter movement patterns, provides backhauls that reduce bottlenecks and assists mobile users to only scan for and connect to WiFi networks when it actually benefits. This holistic approach would help reduce peak loads on service provider networks, protect end-user data-caps, increase data throughput for mobile users and help reduce energy consumption by eliminating unnecessary network operations.

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