ENHANCING WI-FI WITH IEEE 802.11U FOR MOBILE DATA OFFLOADING

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ABSTRACT

Apart from voice services, data made its foray in cellular networks with 2.5G networks. Today, with 3G network already in place, the data requirements of mobile subscribers is very high. With the increasing demand for mobile internet and rich data services such as streaming media for audio and video, this data requirement is expected to multifold in near future. Correspondingly the network operators have started looking for alternative means of satisfying these data needs. Among many alternatives, mobile data offloading (MDO) is the most promising one. This paper presents the extensive need, benefits, and technological solutions for MDO. Qualitatively, it is also shown that Wi-Fi, or 802.11 network is the most promising technology for MDO. Also, to further popularize Wi-Fi as a candidate network for MDO, IEEE published the enhancements to the base IEEE 802.11-2007 standard in the form of its ninth amendment (i.e. IEEE 802.11u). Restricting the scope to beacon frame only, we show how this amendment supports interworking of 802.11 network with external networks. We also show the benefit of 802.11u compatible Wi-Fi, as a candidate network for MDO, by modelling the problem of taking user's choice for assisting any vertical handover decision algorithm.

KEYWORDS

Wi-Fi, IEEE 802.11, Mobile Data Offloading, 3G, IEEE 802.11u.

1. INTRODUCTION

Wireless cellular network now covers most of the populated-part of the world. According to the Information and Communication Technology (ICT) statistics, access to mobile networks is now available to 90% of the world population and 80% of the population living in rural areas. In fact, mobile cellular growth has started slowing in developed countries and is slowly reaching saturation levels with an average 116 subscriptions per 100 inhabitants at the end of 2010, just a marginal growth of 1.6% from the year before [1].

For many years in the past, the cutting edge services provided by cellular network were voice and SMS. But mobile phones – especially smart phones and iphones - radically changed it and are now poised to take over the traditional information access devices as the dominant platform for accessing the information. The nature of data transformed from conventional and plain text to emails, multimedia and chats. Subscribers now have an easy access to streaming media for video and audio. So, now apart from voice services, it is the data services which govern the telecom industry. To facilitate these, many countries have already started offering 3G services and people are moving rapidly from 2G to 3G platforms in both developed and developing countries. In fact, in 2010, there were 143 countries offering 3G services commercially, compared to 95 in 2007 [1].

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It is also been speculated that in future no single existing wireless network technology can simultaneously provide low latency, high bandwidth, and wide-area data service to a large number of mobile users [3]. Among many alternatives, offloading the data onto some secondary network is a promising solution. In this paper we emphasize that over the years Wi-Fi network has emerged as the best technology for Mobile Data Offloading (MDO). 3G subscribers have been using Wi-Fi network for satisfying the internet related activities. But with the enhancements proposed in the ninth amendment of IEEE 802.11-2007 standard [14] (also referred to as IEEE 802.11u [15]), this usage of 802.11 network is further expected to increase. This is because 802.11u is capable of providing interworking-specific necessary information in the beacon frame to enable the mobile devices to decide upon the network to connect to before attempting association. With it, roaming partnerships among 802.11 service providers and external subscription service providers can be established and can be advertised in the beacon frame.

The rest of the paper is organized as follows. Section 2 shows the issues with 3G networks which are required to be resolved. Section 3 shows possible solutions and Section 4 shows that among Fem-to-Cell and Wi-Fi as the candidate technologies for MDO, why Wi-Fi should be preferred. In Section-5 we show the enhancements proposed by 802.11u in the beacon frame of IEEE 802.11 standard to support interworking with external networks. In Section-6 we show one of the utility of these proposed enhancements by modelling the problem of capturing user preferences for vertical handover decision.

2. PROBLEMS WITH 3G NETWORK

In this section we show that why there is a problem and exactly where the problem lies.

2.1. Why there is a Problem:

Following are the three basic reasons which contribute to why current 3G network infrastructure cannot sustain to the future bandwidth requirements:

1. **Increasing Network Traffic**: 3G offers rich data services and the bandwidth consumption from these is not expected to slowdown. Let us see few statistics in support this point:

• According to Cisco Systems, in 2015 mobile data traffic will be 26 times higher compared to 2010, mainly caused by the use of mobile video services [5].

• Mobile data traffic will grow at a compound annual growth rate (CAGR) of 92 percent from 2010 to 2015, reaching 6.3 hexabytes per month by 2015. The data capacity requirements are increasing 150 percent per year [6].

• Juniper Research estimates that the cost of delivering mobile data could rise sevenfold to $370 billion by 2016 [4].

Thus, using current 3G network infrastructure and architectures, the cost of supporting the anticipated growth in traffic generated from mobile data services is unsustainable. This subsequent anticipated explosion of data traffic on 3G networks has caused an immediate need for carriers to seriously think of the alternatives so that both voice and data services can perform optimally.

2. Increasing usage of Smart Phones: Accelerated adoption of Smartphone by mobile phone subscribers, in combination with the much higher usage profile of Smartphone relative to basic handsets is one of the major cause for the unexpected data surge. Operators are seeing increasing data traffic driven by the growth of Smartphone's and other connected devices that offer ubiquitous Internet access. Let us see again few statistics in support of this point:

- According to Juniper Research the amount of mobile data traffic generated by smart phones, feature phones and tablets will exceed 14,000 Petabytes by 2015, equivalent to almost 18 billion movie downloads or 3 trillion music tracks [7].

- Informa Telecoms and Media data indicates that the number of Smartphone in use grew by 32 percent during the year 2010 while it was anticipated as 22 percent [8].

- In developed countries the maximum of the mobile subscribers have an internet ready phone. In fact in US and Western Europe this number is about 90%.

- 98 percent of iPhone users use the data features of their phones. iPhone users are four times as likely to use the Internet as a typical subscriber, five times as likely to download an application, six times as likely to watch mobile video, and seven times as likely to use location based services [9].

Above all, out of total global handsets in use today, Smartphone represent only 13 percent but they represent over 78 percent of total global handset traffic [5].

3. Spectrum is Costly and Scarce: Telecommunication systems all require a certain amount of electromagnetic bandwidth to operate. In different parts of the world, different organizations allot parts of the overall electromagnetic spectrum to different uses. Also, in many parts of the world, international agreements are required so that communications systems in neighboring countries are not interfering with each other. As the world becomes increasingly wireless (with cordless phones, cell phones, wireless internet, GPS devices, etc), allocation of the available spectrum to each technology becomes increasingly contentious. Each user community (usually manufacturers of the wireless equipment) wants more bandwidth in order to be able to sell and service more units.

So "Spectrum scarcity" is the apparent result. This requires that the means of allocation of radio communications resources to satisfy our future need for increasingly dense, fast, flexible mobile communications networks should be done judiciously. Because of this scarcity, the organizations allotting this spectrum to vendors charge them heavily.

2.2. Where is the Problem?

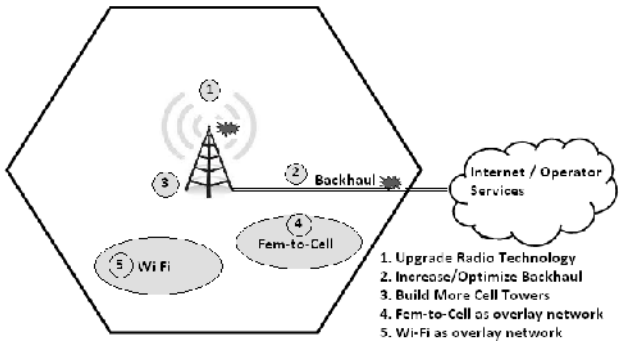

Fig 1. Backhaul and Radio are two choke points.

Fig 1 shows exactly where the problem lies with respect to 3G network infrastructure and the possible solutions. There are two choke points, i.e. Radio and Backhaul (point 1 and 2 in Fig 1). These are the limiting factors for the amount of data traffic which can pass from Internet/Operator network to the end user. Increasing their capacity can alleviate the problem temporarily but certainly cannot provide a permanent solution.

3. POSSIBLE SOLUTIONS

The possible techniques to solve the problem and the issues associated are as follows:

1. Scaling: It refers to building more cell towers and/or increasing the backhaul capacity. But this approach requires more infrastructure and thus more investment, which directly results in high cost/MB. Moreover, research reveals that top 3% of the smart phone users consume 40% of all smart phone data [2]; the main user gets a fractional benefit as the major consumers will continue to hog the increased bandwidth. So, scaling is not the solution, rather it is just masking the problem.

2. Optimization: It refers to optimizing the radio and backhaul usage. Starting from 1G to 3G many technological upgrades have happened for the optimized usage of radio [10], but there is certainly a limit on the number of bits which can be packed onto radio waves. Moreover, the rate of data consumption will continue to outpace technology upgrades as host of new services are introduced with any technological upgrade. Also, any technological upgrade results in new equipments to be installed, which again require more investment.

Backhaul usage can also be optimized and caching frequently used data items is one way to do it. It is a promising solution as it helps in flow control, but it poses two challenges:

a) Intensive packet inspection and correlation, which may slow down the network.

b) Privacy issues, as users do not like to be policed.

3. Mobile Data Offloading (MDO): It is the use of other (preferably "complementary") network technologies for delivering data originally targeted for cellular users. It provides an alternative path of wireless delivery with a best performance capability. These networks can function with the macro-cellular network as an adjunct network either operating independently or as an overlay network. It is a new telecom industry buzzword, which is soon expected to become its separate revenue generating segment.

It has emerged as a promising solution. Though necessary, it is beneficial also. For the end users offloading contributes in higher bandwidth availability and reduced data services cost. For the operators its main contribution is in reducing the congestion of the cellular networks. Because a good amount of the telecom operators' revenue goes in paying for the exclusive usage of the spectrum, offloading also helps in reducing this cost without affecting the services.

4. TECHNOLOGIES FOR MOBILE DATA OFFLOADING

The two candidate technologies for Mobile Data Offloading are:

1) Fem-to-cell: It is a small cellular base station, which connects to the service provider's network via broadband, and is typically designed for use in a small business or home. It allows service providers to extend their services where access would otherwise be limited or unavailable.

It leverages on the licensed spectrum, offer better indoor coverage at low pressure and work with common single radio handsets.

Fem-to-cells are the natural extension of the main cellular network which allows them to support most of the services provided by mobile operator. Since wireless interface in Fem-to-cells is identical to cellular network, and control functions are also identical, this does not require handsets to have an additional Wi-Fi radio unit enabled. Moreover, Fem-to-cells allow for easier seamless roaming, and can provide managed quality of service, and provides improved battery life.

On the contrary, the main challenge with Fem-to-cells is that they have yet not reached widespread availability. They require expensive devices because the market is still small and since because of the issues of utilizing licensed spectrum, FCC rules etc, there deployment is more complicated. There may be spectrum conflicts between the macro network and fem-to-cell and between neighboring fem-to-cells. Most important, they still use the same spectrum of cellular service providers for satisfying the data needs of the subscribers.

2) Wi-fi: Based on IEEE 802.11, it is a name of a popular wireless networking technology that uses radio waves to provide wireless high-speed Internet and network connections. It leverages the unlicensed spectrum; and offer a much faster rate of service than the comparable 3G service.

4.1 Why Wi-Fi is the right Technology ?

Though 3G-WLAN interworking should be built on top of harmonizing layer(s) (e.g. IP) and not limited to any specific WLAN technology, Wi-Fi has emerged as one of the primary candidate for offloading data. Following are the factors which contribute to the huge success of Wi-Fi.

1) Vast unlicensed spectrum: Wi-Fi operates in unlicensed ISM 2.4 GHz and 5 GHz frequency bands. The spectrum availability in the two respective bands is 83 MHz and 505 MHz. This means that regulator approval is not required for individual deployments, and Wi-Fi has a larger "free" spectrum available to cater to any size of network deployment.

2) High data rates and user experience: Though ITU has not provided a clear definition of the data rates which a user can expect from a 3G service provider, it is expected that IMT-2000 provides the minimum transmission data rates of 2 Mbit/s for stationary or walking users, and 384 Kbit/s in a moving vehicle [11]. Compared to this, IEEE 802.11n, which operates on both the 2.4 GHz and 5GHz band, can provide the theoretically maximum data rates up to 600 Mbps [12]. So for consumers, all this it means is that in terms of downloading music or streaming video, or transferring a big file, Wi-Fi is a much better network solution.

3) Total ownership cost: Wi-Fi offers huge capital expenditure and operational expense benefits for operators. Over the last decade, since the launch of Wi-Fi technology, it has evolved and matured enough, thus bringing down the equipment cost significantly. In addition, with data rates of 600 Mbps and availability of more than 500MHz of unlicensed spectrum, Wi-Fi offers huge network capacity compared to 2G/3G, thus requiring less equipment to serve a given subscriber base. Also, without requiring large investment in channel planning and site surveys, the Wi-Fi networks can be easily and cost-effectively scaled.

4) Advanced Security and QoS: Since the introduction of the IEEE 802.11 WLAN standard in 1999, it has gone through a series of amendments to support quality of service (QoS) along with the standard-based business-grade security. With the most common wireless encryption standard, Wired Equivalent Privacy (WEP), been shown to be easily breakable, the advent of Wi-Fi

protected access (WPA and WPA2) encryption aimed to solve the problem. WPA2 is based on IEEE 802.11i and it provides 128-bit AES-based encryption using Pre-Shared Key (PSK) or 802.1x RADIUS authentication, which is ideal for operators to provide Authentication, Authorization and Accounting (AAA) services. The Wi-Fi Multimedia enabled Wi-Fi networks offer a prioritized treatment to multimedia applications such as VoIp, interactive gaming, and video streaming, to support the jitter and latency requirements of these applications. As a result, QoS and security support in Wi-Fi is comparable to that of 2G/3G networks.

5) Increasing number of Wi-Fi hotspots: Wi-Fi operates in more than 220,000 public hotspots and in tens of millions of homes and corporate and university campuses worldwide [13]. There are about four million hotspots around the world and as more large venues and enterprises recognize the significant value of offering Wi-Fi for their customers, employees and operations, the number of hotspots is growing rapidly.
Also, AT&T's Q3 2009 hotspot connection numbers were 25.4million sessions, up from 15 million the quarter before. Of these connections, 60% were from “integrated devices”, meaning Smart phones [13]. It is estimated that in 2015 wireless hotspots will account for nearly 120 billion connect sessions [13].

6) Wi-Fi Complement to 3G: MDO prefers complementary network technology to 3G for delivering data. Over the years Wi-Fi has proved to be complementary technology to 3G and there are several important ways in which Wi-Fi and 3G approach of offering wireless access services are substantially different.

First, the corresponding network deployment and business models are different. The basic business model of 3G is the telecommunication service model in which service providers own and manage the infrastructure and sell service on it. In contrast, Wi-Fi favors data communication industry (LANs). The basic business model is the equipment makers selling equipments to customers and services provided by the equipment are free to its customers. Second, 3G mobile technology use licensed spectrum, while Wi-Fi uses unlicensed shared spectrum. Thus there cost of service and quality of service are different. Third, the standardizing bodies of two are different. 3G is been standardized by 3GPP and is a relatively small family of internationally sanctioned standards. In contrast, Wi-Fi is one of the families of continuously evolving 802.11x wireless Ethernet standards. Finally, 3G offers communication in much broader geographical area with ubiquitous services, but at comparatively less speed. In contrast, Wi-Fi offers communication in smaller geographical area, but at very high speed.

5. ENHANCEMENTS PROPOSED IN IEEE 802.11U

Here we limit the discussion to the enhancements proposed in the beacon frame only. This is because to implement MDO many issues are to be taken care of. One such major issue is to select a best Wi-Fi network out of many available Wi-Fi networks by the mobile device to which the access control can be passed on. This network selection generally happens on the fields of beacon frame because it is the beacon frame which advertises the information related to the network.

IEEE 802.11u [15] is the ninth amendment to IEEE 802.11-2007 standard and specifies enhancements to IEEE 802.11 Medium Access Control (MAC) that supports wireless local area network (WLAN) interworking with external networks. Interworking service facilitates network discovery and selection, enabling transfer of information from external networks, enabling the emergency services via 802.11 network, and interfacing subscription network service provider networks (SSPNs) to 802.11 networks. It allows the insertion of following four information element fields in the frame body of the beacon frame to facilitate the mobile device in selecting the network prior to association.

a) Roaming Consortium Information Element: Roaming consortium is defined as a group of subscription service providers (SSP's) with inter SSP roaming agreement. The security credentials of this roaming consortium can be used to authenticate with the access point transmitting this element. By embedding this information element in the beacon frame, 802.11 network can advertise up to three organizational identifiers which facilitates a mobile device to choose a 802.11 network with known roaming consortium or SSP. If there are more than three roaming consortium, they can be queried by the mobile device using Access Network Query Protocol (ANQP).

b) Interworking Information Element: Here the following interworking service capabilities of an 802.11 network can be advertised. First, it contains *Access Network Type* field using which one of the following type of access networks can be advertised: Private network, Private network with guest access, Chargeable public network, Free public network, Personal device network, Emergency services only network, test or experimental network, or wildcard network. Second, the information about whether the 802.11 network provides *connectivity to the internet* or not can be advertised. Third information which can be advertised is about whether the network can be accessed directly or additional step is required for accessing the network. This field in 802.11u terminology is called as *ASRA (Additional Step Required for Access).* Fourth, it can contain the information about whether the *emergency services* are reachable via the 802.11 network or not. Fifth, the information about the *venue* can be embedded where the Access Point transmitting this beacon is located.

c) **Advertisement Protocol Information Element**: It contains information to identify a advertisement protocol which can be used.

4) **Emergency Alert Identifier Information Element**: It provides a hash to identify instances of the active EAS (Emergency Alert System) messages that are currently available from the network.

6. MODELLING USER'S CHOICES FOR VERTICAL HANDOFF DECISION

Vertical handoff is the process of selecting and connecting to a network, other than the one to which the mobile device is presently connected to. For example, a mobile device connected to a UMTS network and downloading a file when comes in the vicinity of 802.11 network can perform vertical handoff and connect to the Wi-Fi network. Vertical handoff involves *handoff decision* which is to select a most appropriate network out of all the networks available. Many handoff decision algorithms are proposed in the literature which varies on the decision parameters considered by them (for example: jitter, bandwidth, latency, bit error rate etc) and handover decision algorithms/techniques used by them.

Since one of the most important purpose of vertical handoff is satisfying the user, the user's choice about various issues should be captured. For example, if Security of the network and cost of using the network are two parameters then for different users the choice amongst two may vary. Person X would like to connect to a secure network and willing to pay more. Rather person Y would prefer a cost effective network and security may not be the big issue. Many authors have considered capturing this user's choice in there respective vertical handoff decision algorithms on many diverse criteria's. For more information on these, [16 - 21] may be referred.

Since 3G-WLAN interworking architectures should preferably be based on corresponding standards [24], and the enhancements proposed in 802.11u are expected to further boost the popularity of Wi-Fi networks as the most promising candidate technology for MDO, we show how user's choice can be captured on the features of 802.11u compatible beacon frame. We

propose to use Analytical Hierarchy Processing (AHP) for it. For more information on AHP, [22] may be referred. As shown in Figure-2 the following criteria and sub criteria are selected:

Roaming Consortium (RoCo): Using this the user can prefer to connect to a network which has a known RoCo. For example, user can prefer a network which has a roaming partnership with the corresponding 3G service provider.

Internet Connectivity Provided (ICP): The purpose of 802.11 network, or WLAN, is to provide a local area network in a wireless fashion. Whether this WLAN provides internet services or not is the decision of the network service provider, or network owner. Using ICP feature advertised in the beacon frame the user can give the preference to connect to a WLAN which provides internet connectivity.

Access Network (AN): This field of 802.11u advertises about the type of access network. There are eight different types of possible networks which can be advertised. But for data offloading, the following four types are selected: Private Network (PN), Private Network with Guest Access (PNGA), Chargeable Public Network (CPN), and Free Public Network (FPN). The user can prefer to connect to one type of network over the others.

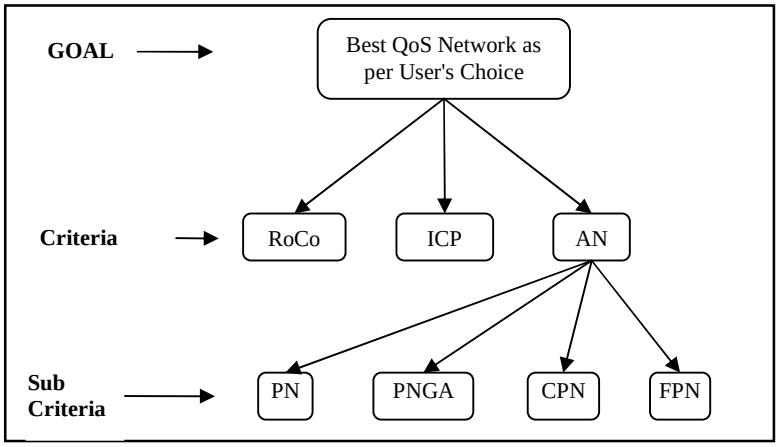

Figure-2. AHP decision Tree for capturing User's Choice on IEEE 802.11u fields.

7. EXPERIMENTAL SET UP AND RESULTS

For illustrating the ranking of networks on user's choice, we asked three users to give there respective choices. These participants were heavy users of 3G data services and were aware of the AHP process. They gave the preferences by filling up the upper triangle of the matrices corresponding to the three criteria and four sub-criteria of figure-1. The service type for which the three users gave there choices falls into the category of Streaming Class of 3GPP TS 23.107 [23]. Using AHP, these choices were converted into corresponding eigen vectors and Table-1 shows these eigen vectors. These eigen vectors represent the ranking of three criteria and four sub-criteria for corresponding user.

Table-1. Eigen Vectors for Criteria and Sub-Criteria of Figure-2.

	Eigen Vectors for Criteria's			Eigen Vectors for sub Criteria's			
	AN	**RoCo**	**ICP**	**PN**	**PNGA**	**CPN**	**FPN**
User1	0.7235	0.1932	0.0833	0.0622	0.1079	0.2671	0.5628
User2	0.1062	0.2605	0.6333	0.1370	0.1954	0.2480	0.4195
User3	0.1698	0.4428	0.3873	0.1429	0.2184	0.0709	0.5676

Table-2 shows the values of the parameters extracted from a 802.11u compatible beacon frame. Type of network indicates that out of four types, which type of network is this. This is used while making the matrix of alternatives for the four sub-criteria's of Figure-2. For example, N1 is a Private Network (PN). So while making the matrix of alternatives for sub-criteria Private Network, the weight of N is kept as 9 (highest weight as per AHP) with respect to other networks. Roaming Consortium shows whether known roaming consortium is advertised or not. Value 1 indicates a known Roaming Consortium. Similarly, value 1 in the Internet connectivity Provided indicates that the network provides internet connectivity.

Table-2. Advertised networks and the values of fields extracted from the corresponding Beacon.

Network	Type of Network	Roaming Consortium	Internet Connectivity
N1	PN	0	1
N2	FPN	1	0
N3	CPN	1	1
N4	FPN	0	1

The networks were ranked by applying the AHP process and Figure-3 shows the results. It shows that for User-1 the most preferred network is N2, for user-2 and User-3 it is N3. These results are inline with the choice of the user. For example, User-1 preferred very strongly a Free Public Network (as maximum weight is assigned to ANT and to FPN) and which should have known Roaming Consortium (as second highest preferred criteria is RoCo). The selected network N2 has both the traits. Similar are the results for User-2 and User-3.

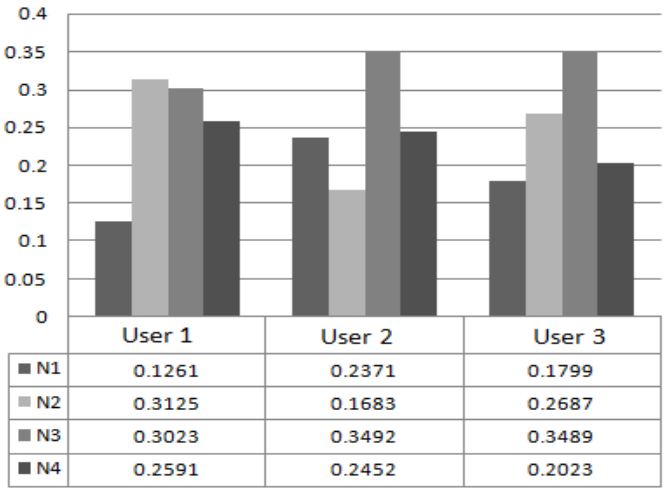

Figure-3. Ranking of Networks for User-1, User-2, and User-3.

5. CONCLUSION

With the expected increase in network traffic, increasing usage of smart phones, and considering the fact that spectrum is costly and scarce, Mobile Data Offloading (MDO) is the new buzzword in the telecommunication industry. In this paper, several qualitative reasons and statistics are given in support of it. Also, the benefits and drawbacks of Fem-to-Cell and Wi-Fi, the two candidate technologies for MDO, are presented. Based upon the comparative analysis it can be said that a typical customer who don't want to pay for a dual mode smart phone or iphone, is a little technical savvy, want to get good coverage of network at home (which otherwise is bad), Fem-to-cell is a good solution. Rather, considering the continuous increase in usage of smart phones and iphones, and projected increase in the data requirements of mobile subscribers in future, Wi-Fi is the clear winner. We have also shown the efforts of IEEE in promoting Wi-Fi as a candidate technology for MDO in the form of publishing the ninth amendment (802.11u) to 802.11-2007 standard. To show the usage of 802.11u, the problem of capturing the choice of users for assisting vertical handoff is also modelled and simulated the ranking of available 802.11 networks using this model.

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