Sharing your Urban Residential WiFi (UR-WiFi)

Santosh Kawade, Jan-Willem Van Bloem, V.S. Abhayawardhana, D. Wisely
BT Mobility Research Unit, Rigel House, Adastral Park, Ipswich IP5 3RE, UK.
{santosh.2.kawade,viraj.abhayawardhana,dave.wisely}@bt.com
{j.w.h.vanbloem}@student.utwente.nl

***Abstract*— Cheap and ubiquitous broadband wireless access is what most of the operators are aiming for. This paper analyses an innovative proposal to extend the traditional fixed coverage offered by residential broadband into an urban wireless coverage using Urban Residential Wireless Fidelity (UR-WiFi) project. UR-WiFi assumes that by giving some incentive, the broadband customer would extend his surplus broadband and wireless bandwidth for public usage. The study performs a feasibility study of coverage, capacity and interference modelling based on different 802.11x technologies. In-depth technical analysis is complimented with detailed analytical and experimental data and is extrapolated on a countrywide basis. Based on results, we believe UR-WiFi provides a viable option for next generation broadband wireless access.**

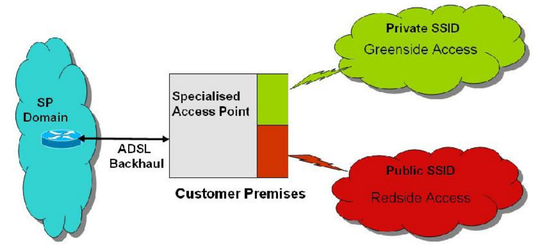

Fig. 1. UR-WiFi Architecture

I. Introduction

Fixed operators have understood the value of mobility placed by customers and are in race to provide fixed-mobile converged services. Wireless LAN (WLAN) is one of the fastest and the cheapest broadband access system. Earlier there has been research conducted on similar topics by several authors, but they have been limited to some specific areas such as WLAN evaluation in corporate environments [1] or location of APs [2]. They fall short of addressing the complete technical problem. Though WLAN have a limited coverage, certain contributing factors have given us an opportunity to look at this limitation in a different perspective. These factors are; a) High urban density in many European countries (for example 90% of UK's population is concentrated in cities with just 10% of its land area) [3] or upto 65% - 70% of customers are contained within 1000 exchange areas only b) High broadband deployment in urban areas (around 10 million broadband lines deployed in UK [4]) c) Rapid WLAN adoption rate with heavy subsidisation of Access Points (AP) by operators. Currently there are more than 10K WLAN hotspots and around 1 million residential APs deployed in the UK. d) Availability of WiFi capability in next generation handsets and Personal Digital Assistants (PDAs) e) Uses the license-exempt spectrum and has low infrastructure costs f) Significant mobile calls (approx. 70%) being made at home or in urban environments [5]. The concept has already undertaken seriously by industry, one example is FON community [6].

Figure 1 shows the UR-WiFi architecture. A specialised AP or hub is deployed in customer premises that supports two networks; a private network for indoor usage like home networking and a public network for outdoor usage on streets and in neighbourhoods. The private network is shown as the green cloud, while the public network is shown as red cloud. The AP's wireless broadband connection and the Asymmetric Digital Subscriber Line (ADSL) backhaul capacity is sufficient to carry traffic on both networks. The traffic on the networks is kept separate, providing adequate security measures to all users. The UR-WiFi AP also takes care of implementing network Quality of Service (QoS) features, admission control, multiple Service Set IDentifiers (SSID), etc but they are beyond the scope of this paper.

This study aims to find answers to fundamental questions like - a) The WiFi technology used by the AP b) The density and distribution of access points needed in totality to provide sufficient coverage and capacity in urban areas b) The impact and evolution of interference for a given WLAN adoption rate c) The impact on system performance due to different house geometries and environments d) The importance of AP placement in the house e) The suitability of 5GHz band/2.4GHz band or both f) The achievable performance for different voice, video and data services.

The paper is divided into following sections. Section II describes the technical analysis done for studying the feasibility of UR-WiFi concept on the basis of a radio propagation model, section III provides the test results based on field measurements and refinement of the RF model, section IV provides the extrapolation of the test results to a wider scale and plots maps of aggregate UR-WiFi coverage and finally section V provides the conclusion of the study.

II. Technical Analysis

An urban residential environment constitutes of different house types such as bungalows, semi-detached, detached, flats, etc. A theoretical propagation model is defined for an urban street environment. In the model, performance of the WLAN was analysed inside the house, in neighbouring houses

0-7803-9392-9/06/$20.00 (c) 2006 IEEE

and along the street in presence of other WLAN deployments. An appropriate radio propagation model based on the Mixed indoor-outdoor model [7] and Multi-Wall-Floor(MWF) model [8] is developed and used for link budget analysis. A theoretical model is developed in which the pathloss between outdoor transmitter and indoor receiver is calculated as [7]

$$L = L_{micro} + L_{OW} + \sum k_{wi} L_{wi} + a * R \qquad (1)$$

where, L_{micro} is the micro cell pathloss based on Universal Mobile Telecommunications System 30.03(UMTS) Outdoor to Indoor and Pedestrian Test Environment pathloss model, L_{OW} is the outdoor wall penetration loss in [dB], R is virtual transmitter-receiver separation given in metres, k_{wi} is the number of penetrated walls of type i, L_{wi} is the loss of wall type i and a is attenuation in [dB/m], equal to 0.8

The RF model takes into account nonlinear relationship between the cumulative penetration loss and the number of penetrated floors and walls and is given by [8]

$$NL = L_s * n_s^{\left[\frac{(n_s+5)}{(n_s+3)} - b\right]} \qquad (2)$$

where, NL is the Non linear wall loss in dB, Ls is the Loss per wall in dB, n_s is the number of walls of same type and b is the empirical constant equal to 0.5 A general estimation of street coverage and capacity was made based on the theoretical model.

III. Field Measurements

Radio measurements performed in a representative street environment was used to validate and refine the theoretical RF model. Site surveying tools such as Ekahau and Netstumbler [9] were used for test measurement. Performance evaluation of different 802.11x technologies for different devices and services was done. Effect of interference such as Adjacent Channel Interference (ACI), Co-Channel Interference (CCI), Bluetooth, Video senders was measured.

Following is the summary of the test environment. Tests for data and video services were performed using Dell/Sony laptops and Toshiba PDAs, O2 XDA II. The services tested on these devices were browsing, ftp upload-download and video streaming. Voice service was tested using HTC Tornado mobile phones and PDAs with the Skype application. Belkin and Netgear kits were used for evaluating the performance of 802.11pre-n with Multiple Input Multiple Output (MIMO) antenna technology, while Cisco Aironet 1200 kits were used to evaluate 802.11g/a. D-link class 2 Bluetooth USB dongles and Philips video senders were used as external interference sources along with other WLANs.

A. Measurement results

In the test setup, the AP was placed inside the house. Capacity and coverage tests were performed both indoors and outdoors for 802.11pre-n, 802.11a and 802.11g. Based on the measurements it was found that 802.11pre-n technology out performs 802.11g and 802.11a. Figure 2 shows that outdoor range of 802.11pre-n is around 70m as compared to 30m and 25m for 802.11g and 802.11a respectively. 802.11pre-n provides excellent indoor bandwidth of around 25Mbps and outdoor bandwidth of 6-8Mbs as compared to the 2-5Mbps for 802.11a/g technology. High throughputs were available within few meters of the AP for all three technologies. One key finding was the significance of AP placement in the house. Measurement results showed that a sub-optimally installed AP severely degrades the outdoor coverage. Reduction of about 50% of the original outdoor cell size was observed when an AP is placed in a middle room instead of outer room, i.e. the room closer to the street. In many cases the selection of installation point would be beyond control of operator and sometimes beyond control of the owner as well, hence the need of repeaters is recommended in such situations. It was further found that cell size for video and audio services were approximately 70% of the data cell size for all three technologies.

Interference poses a serious problem for UR-WiFi project. The 2.4GHz unlicensed band is crowded with growing number of devices. Interference degrades the performance and affects the service level agreements with the client base. Tests were conducted to understand and measure the impact of interference. Figure 3 shows the WLAN deployment in a local area using Ekahau tool and GPS receiver. The nearby WLANs introduce the adjacent and co-channel interference problem

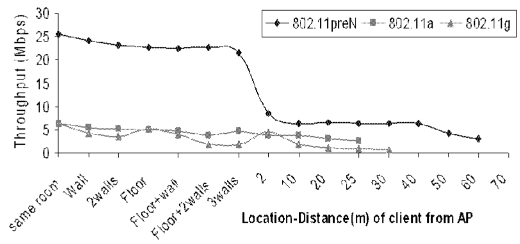

Fig. 2. Evaluating 802.11x technologies for capacity and coverage

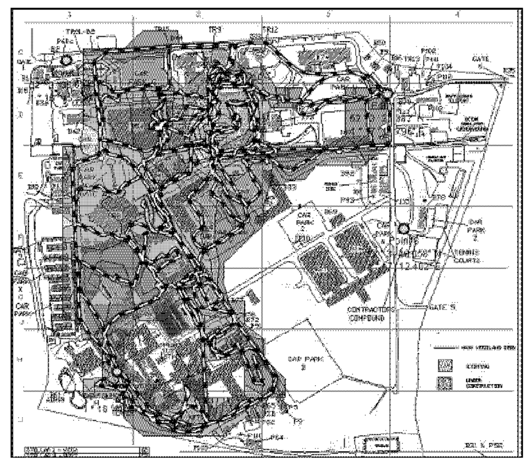

Fig. 3. Radio coverage of campus WLAN deployment

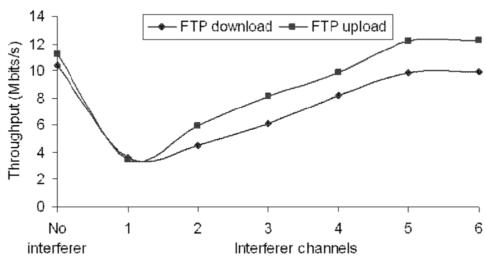

Fig. 4. Impact of Adjacent Channel Interference

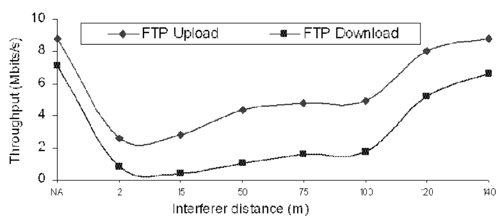

Fig. 5. Impact of Co-Channel Interference

and is shown in the green shades of the map.

ACI is the interference caused by adjacent channels that have spectral overlap in frequency domain of the client channel. The client is the device whose performance is being measured in presence of interference. In the test setup, the 2 WLANs were setup in neighbouring houses of a terraced environment, one acting as the interfering WLAN. The client AP and interference AP were located inside the houses. Client was running outside the house on channel 1. The performance of client was measured without interferer being active. The interferer was switched on at a street distance of 12m away from the client on channels 2 to 6. Figure 4 shows the impact of ACI. The client throughput was about 10-12Mbps without interference but degraded to 5-6Mbps when the interferer was occupying the next adjacent channel. The results were repeated for different distances between client and interferer but results are not shown here.

CCI is the interference caused by nearby WLANs that are using same channel or frequency of the client channel. In the test setup the 2 adjoining WLANs were setup on channel 1, one acting as interfering WLAN. The client was at street distance of 20m from its connected AP. Performance of the client was measured with interferer being moved away from client at a distance of 2m to 140m . Figure 5 shows the impact of CCI where throughput degrades to about 1/3rd from 7-9Mbps to 2-3Mbps but improves with increasing interfering distance. Other sources of interference such as from Bluetooth, video senders were studied as well. Key findings are presented below.

Video senders - Video senders are devices that interconnect audio/video source such as cable, DVD, VCR to TV sets wirelessly in a home environment. It operates in the 2.4Ghz

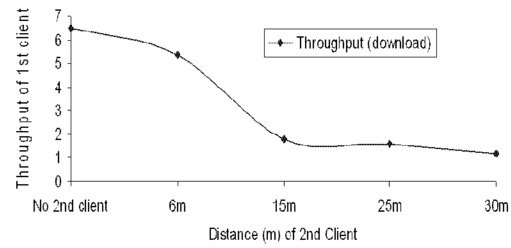

Fig. 6. Near-Far effect

band. In the test setup a video sender and a receiver were installed in two rooms connecting two TV sets. A WLAN was operational on the same channel. It was found that when the TV sender was switched on, the throughput of operational WLAN dropped to zero. The outdoor range of the video sender can be upto 10m and hence may affect neighbouring WLANs as well. Though there are 4 channels on TV sender, it reduces the frequency reuse factor while performing channel management for blanket WLAN deployment. In a test setup, three class-2 Bluetooth interferers were transferring data files within 5 metres from an AP. The AP throughput was degraded by 2-3 Mbps due to Bluetooth interference.

Near far effect : Clients on the street (i.e. public network) would be connected to UR-WiFi AP and hence its important to understand how that affects the in-house users (i.e. private network). In the test setup, 2 clients each from private and public network are connected to UR-WiFi AP. The public network client is moved from 6m to 30m away on the street and performance of private network client is measured. Figure 6 shows the throughput of in-house client degrading from 6Mbps to 1.5-2Mbps as the public network client connects at increasing distance from the AP. This is due to increased time slots needed for the far away client to send its data at a particular bit error rate. This results in non-uniform sharing of air channel bringing down the performance of nearby clients. The QoS of in-house clients needs to be guaranteed with configuration of UR-WiFi AP to take care of this problem. Measurements have shown that 802.11pre-n performs better than 802.11g/a on various fronts and is the first recommendation.

- 802.11pre-n coverage is far better than 802.11a which is key factor for the UR-WiFi project.
- 802.11pre-n performs better than 802.11a/g for video and audio services and also handles jitter well.
- 802.11pre-n performs better in presence of ACI, CCI and Bluetooth interference as compared to 802.11g.
- 802.11pre-n is compatible with existing installation base of 802.11b/g.

Technically 802.11a has an edge over 802.11g technology.

- 802.11a technology is not affected by the interference problem as it 5.2 GHz band. There are 13 non-overlapping channels as compared to 3 in 2.4Ghz band.
- 802.11a has a low installation base and hence low inter-

ference problem.
- Range and throughput of 802.11a is comparable to 802.11g.

But on the downside, 802.11a kits are expensive. There are some regulatory concerns about the maximum permissible power at which it can operate in Europe. Additionally 802.11h is still being developed.

802.11g has coverage as well as interference problem, but it is cheap as compared to 802.11pre-n and 802.11a. 802.11b is not considered for evaluation because of its limited capacity for UR-WiFi services. Other findings from the measurements are

- Outdoor cell radii is approximately 75m, 30m and 25m for 802.11pre-n, 802.11g and 802.11a respectively
- Interference specially ACI and CCI is a significant problem for UR-WiFi project
- Near-Far effect has significant impact on performance of private site users

IV. Extrapolation of results

The findings of the test measurements are extrapolated to show coverage at town or city level. The town database is assumed to have information about household density, house layouts, streets, railway lines and rivers. With different towns having different densities, representative exemplar towns are chosen and modelled for UR-WiFi coverage. The test results are extrapolated to a town area with a tool written in MapBasic/MapInfo software.MapInfo is a desktop software to perform mapping and geographical analysis. It includes feature for raster and vector database support, map creation, report and graph creation. MapBasic software is a programming and application development environment on top of MapInfo.

Figure 7 shows top view of a town area. The red lines indicate road edges while the dark brown rectangular objects indicate the outline of houses in the area. In the example shown the total town area is 10.935 sq km and area covered by houses is around 0.638 sq km i.e 5.8% of the total town area. A random number (0 to 1) is assigned for each house/building in the town. WLAN adoption rate or takeup of 1% is chosen for the town and all houses with random number less than the adoption level (0.01) are activated. The channel distribution was based on actual site surveying results done in five different areas of the town. The activated houses are marked with blue, green, red squares representing channels 1, 6, 11 with other shades used for adjacent channels. For the active cells a circular coverage with appropriate radius and channel is plotted. Coverage radius is based on the measurement results, for example 50 metres on average for 802.11pre-n technology. The overlapping coverage areas are merged and aggregrate coverage of active cells is calculated. The circular green shaded zones shown in Figure 7 are the the aggregate UR-WiFi coverage area. In this case with 1% adoption rate around 4% of town area is covered while 12.2% of houses are covered by UR-WiFi deployment. This exercise is carried out for different adoption rates for towns with different household densities and

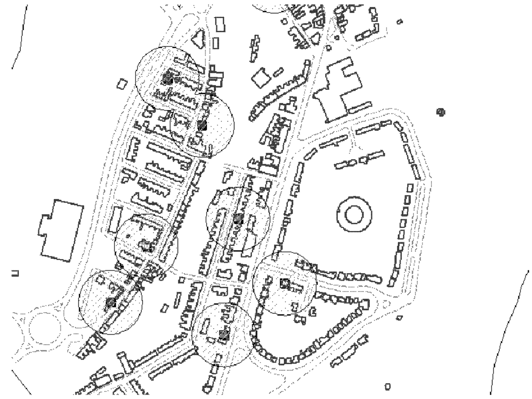

Fig. 7. UR-WiFi coverage map for a town

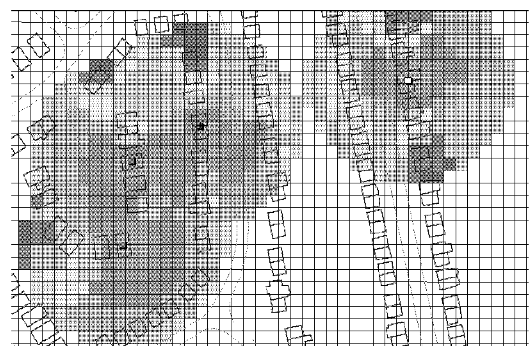

Fig. 8. Pathloss map

the final statistics are gathered. This helps to understand the coverage and number of AP's needed for particular town.

But a circular coverage is just an ideal scenario as the coverage would be affected by house geometry, walls, furniture, AP location, neighbourhood houses, etc. The previous coverage map has a significant error margin, hence instead of plotting circular coverage the environmental parameters are taken into account. The town area is divided into a 5m X 5m size raster grid. Based on the previous RF model described in section II, a pathloss profile cutting through houses, streets is created from each grid cell to its corresponding AP. Based on this profile, pathloss values for each grid cell is calculated. For grid cells in overlapping WLANs, minimum pathloss values are chosen. Different services have different cutoff levels for pathloss tolerance and grid cells with pathloss value exceeding this threshold are marked in a different colour. This exercise creates a pathloss map at a town level that can be used for further analysis such as to determine service and terminal requirements or determine percentage or location of town area where a particular service will work or not. Figure 8 shows a colour coded path loss map for the town. The yellow-orange coloured grid cells signify low pathloss areas while blue/purple coloured grid cells signify higher pathloss regions. This may be due to high number of walls or greater distance between the grid cell and UR-WiFi AP. Statistics about percentage

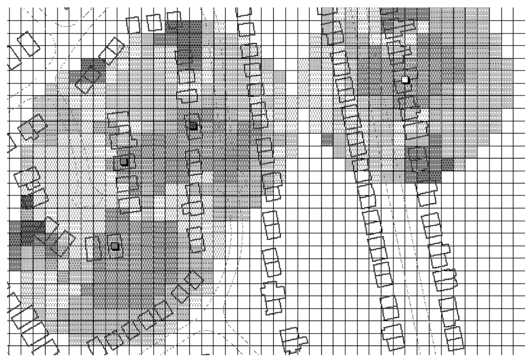

Fig. 9. Interference map (affected grid cells shown in green colour)

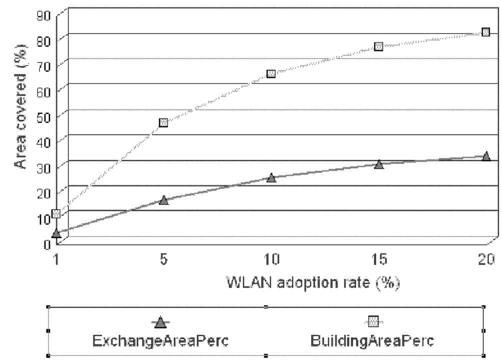

Fig. 10. APs needed for optimal coverage

reduction in coverage of town area and house area because of environmental parameters are generated and compared to previous ideal circular coverage. In this case for a defined cutoff threshold of 105dB, there is reduction of 5.4% in house coverage and 1.07% reduction in town area coverage as compared to ideal scenario. The new results of 3% town area coverage and 6.74% house area coverage are more realistic and correct figures for services with maximum tolerance of 105dB.

WLANs and other devices in the neighbourhood may contribute as interference if they overlap with client channel and this may bring down the system performance. There would be areas that are not able to provide adequate SNR margins because of ACI and CCI caused by adjacent WLANs. For CCI the interfering signals are summed up and accounted as interference in the link budget calculations. For ACI, a weight factor is multiplied to the interfering signal. This factor depends on how far the adjacent channel is from the grid cell channel. Interference is modelled and shown as green regions in the figure 9. This results in a further reduction of 0.7% in house coverage and 0.3% in town area. For a higher WLAN adoption rate the reduction in coverage and capacity due to interference is considerably high. Similary other interferers like Bluetooth, microwave can be modelled as well.

The localised coverage studies and experimental measurements combined with the demographic data can be used to view the likely UR-WiFi coverage across the whole country. This aggregate analysis is considerably accurate and provides with an insight about the expected UR-WiFi topology. Figure 10 shows town area and house area coverage for different adoption rates. Considerable house coverage of around 75% and town coverage of around of 30% is achieved with just 15% of WLAN adoption rate. Based on these results, towns can be ranked and selected for further economic analysis. These localised studies can be extrapolated across the whole country to obtain a considerably accurate UR-WiFi topology.

V. Conclusion

The study provides answers to some of the key technical questions related to public WLANs. It provides a good understanding to problems related to coverage, capacity and interference and gives a positive feedback on UR-WiFi project. It shows, with a modest WLAN adoption rate, a decent broadband wireless network can be built for urban areas. UR-WiFi scores high on the economic side as well. Millions of APs and broadband lines have been deployed. UR-WiFi avoids access network costs by utilizing the previously deployed broadband connections. Other techno-economic comparisons of public WLANs, WiMesh, 3G and 3.5G cellular done at BT [10] have shown that public WLANs is a cost-effective technology in an urban blanket deployment for multimedia and video application whereas 3G is more cost effective in less populated areas and for voice services. The UR-WiFi project operates in license-exempt band. It provides customers with cheaper calls and higher bandwidths. It helps operators to route mobile traffic to their low-cost fixed network and opens new revenue channels for Fixed Mobile Convergence (FMC) services. These favourable technical and economic factors have made UR-WiFi proposal a strong contending technology for next generation broadband wireless.

References

[1] A. Doufexi *et al.*, "An evaluation of the performance of IEEE 802.11a and 802.11g wireless local area networks in a corporate office environment," *Proceedings of the IEEE International Conference on Communication*, vol. 2, pp. 1196 – 1200, May 2003.

[2] N. Cranley, "Model for Wireless LAN Transmitter Location for Optimal Performance," *www.eeng.dcu.ie/~cranleyn/CRANLEY_M801.pdf*.

[3] UK National Statistics, "Population trends," *http://www.statistics.gov.uk/downloads/theme_population/Pop_Trends_91_V3.pdf*.

[4] ZDNet UK, "Uk finally europe's top dog for broadband," *http://news.zdnet.co.uk/communications/0,39020336,39244953,00.htm*.

[5] I. Limbach, "All for one ... and one number for all," *Financial Times*, 29 July 2005.

[6] *http://en.fon.com/*.

[7] "Universal Mobile Telecommunications System (UMTS) Base Station (BS) classification ," tech. rep., 3GPP ETSI TR 25.951 version 6.2.0.

[8] M. Lott and I. Forkel, "A Multi-Wall-and-Floor Model for Indoor Radio Propagation," in *ETSI TR 125 951 V6.2.0*, vol. 0, May 2001.

[9] *http://www.ekahau.com, http://www.netstumbler.com*.

[10] Pete Symth, M Birchler,G Martinez, M Baker, "Future of mobile and wireless communications," *BT Technology Journal*, vol. 21, p. 11, July 2003.