Traffic Measurement for Network Planning of an 802.11-based Operator

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Abstract**--**This paper highlights how an experimental telecommunication infrastructure has been set up and used in order to perform an extensive analysis on a network operator mainly based on the IEEE 802.11 access technology. A traffic measurement testbed is the best way to assess the potential of a network in terms of capacity, performance, etc. We depict how we selected our network elements that reflect the behaviour of a much larger real operator structurally analogous to the smaller sample. In addition to using traffic measurements as a guideline for topology planning, we determine the severity of the impact of other access technologies with overlapping frequency bands. To avoid developing complex mathematical models that reflect the usage patterns of e.g. Bluetooth or Microwave, we perform a set of measurements which show the statistical behaviour of the system. The work done attempts to make use of testbeds to bridge the gap between real measured values and analytically calculated parameters for network planning. Using such an approach in an inductive manner will allow us to optimize the e.g. the network planning process compared to approaches used up to now [1][2][13][14][15].

Index Terms— Testbed, Traffic Measurement Testbed, Next Generation Network, Network Planning, Network Operator

I. Introduction

A lot of research effort has been invested in approaches for quantitative network planning as of a course required by any operator before it can deploy its network and think of revenues. Whereas some efforts use the basic mathematical approach with channel models and recursive algorithms such as in [1] [2] [3] [4], we use the experimental approach, which can be seen as the other end of the problem.

It is pretty intuitive to follow a top-down-like approach when doing an initial analysis for an analytical network that has not yet been built or deployed. The result of such an analysis in an 'initial-indicator' or rough benchmark figure. Sometimes, after such an analysis it is already clear whether or not constructing a particular network is reasonable; as a result, analytical work in the network planning and capacity analysis area serves best as a feasibility study. This is a very important as well as an initial step in the overall process of successfully building and deploying a network, e.g. that of an operator. The 'testbed approach' provides a real measured value vector which can be extended with induction or interpolation giving a clear picture of what to expect when deploying a target network. It has often occurred that systems were designed but turned out to perform in a totally different manner than initially calculated.

II. Design of the 802.11-Based Network Testbed

Let us think of a homogeneous mesh-like network consisting of adjacent Wireless LAN cells to provide coverage and connectivity to mobile users. We are working on the design and realization of such an operator which spans a certain metropolitan area and bases itself on an existing infrastructure [11][12][22]. To clarify the picture, we depict with the snippet below how the operator would look like superficially to a roaming user:

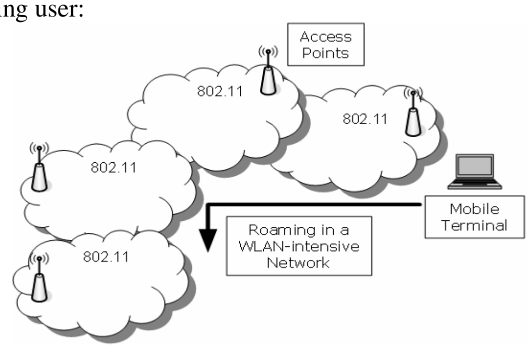

Figure 1: front end of an 802.11 operator as seen by a mobile user

Figure 2 depicts the core structure of our testbed as also highlighted in [6]. We try to incorporate many heterogeneous network access technologies and focus on seamless mobility as dictated by the 4G paradigm. In the current paper however, the specific scope has been simplified as in Figure 3. In our case, it is essential to clearly isolate the part we are working on and which we intend to define as the structure and basic elements of which our 802.11-based operator shall consist.

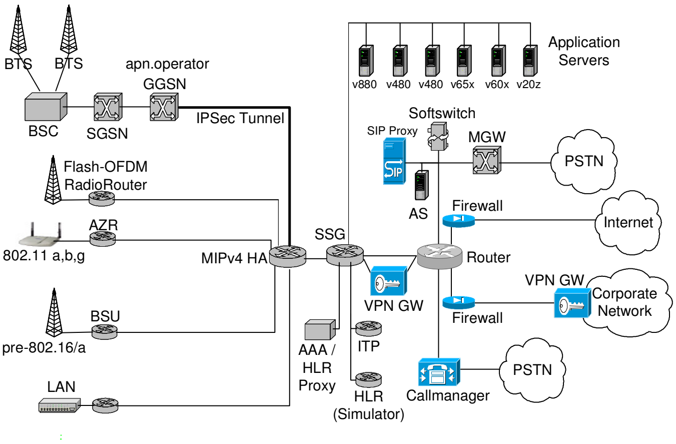

Figure 2: overall testbed topology

Despite the fact that the front end accessible by the mobile users is based on WLAN cells (IEEE 802.11a, b, or g), the backend consists of high-speed wired lines leading to the server boxes for Authentication-Authorization-Accounting (AAA) and user data management on the Home Location Register (HLR) as seen in Figure 3. The propagation path for the operator network consists of the radio part, towards the access points, then via a router responsible for a regional network, then via a central gateway (e.g. a Home Agent) then via a connector to an IP-based service/traffic gateway, and finally the HLR. More details about the architecture of the operator are provided in [6], but we here focus only on the testbed environment, how it is set up and how the traffic measurement testbed serves the purpose of evaluating the potential of an operator. By 'potential of an operator' we mean issues such as: prospect revenues, expected capacity delivery and service guarantees, coverage, stability, and number of supported users at a given time in a particular cell.

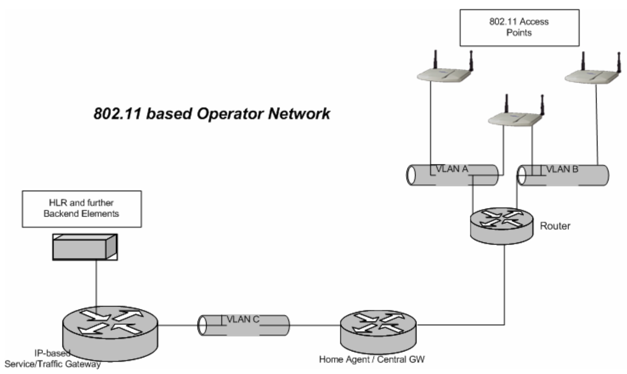

Figure 3: topology of our WLAN-based network operator

An operator would of course have to analyze and then decide where to deploy access points in order to be able to provide optimized coverage to users. Another very important point is to determine how much traffic a certain network can support and eventually how many users it may accomodate simultaneously assuming a certain average resource usage value per user. For instance, in UMTS [21] networks, systems are designed to be able to support around 60% of the overall subscribers in one cell at a time and this is considered as the peak load [21]. The value 60% has been determined statistically. If we heuristically assume a total number of subscribers 'N' to such an operator as the one we describe (which is based on 802.11), then we can uniformly spread N over the total number of cells 'C'. So on the average, we would have N/C users per cell at one given instant in time. This number is sufficient for network planning, because not all users are connected all the time. In addition, WLAN is not scarce in terms of bandwidth as UMTS because the former uses an unlicensed band whereas the latter uses a very expensive frequency band limited in range.

What is of particular interest for such an operator is to consider microwave and Bluetooth interference which impacts WLAN cells using the 802.11b and 802.11g access technologies because they all use the frequency band around 2.4 GHz. As users roam in a metropolitan area connect to WLAN cells, they are under the influence of microwaves and Bluetooth signals from other users in their vicinity, usually within a range of 10-20 meters. Although Bluetooth 2.0 has up to 100 meters theoretical accessibility range, its impact on other signals after the first 20 meters is very weak and almost negligible[20].

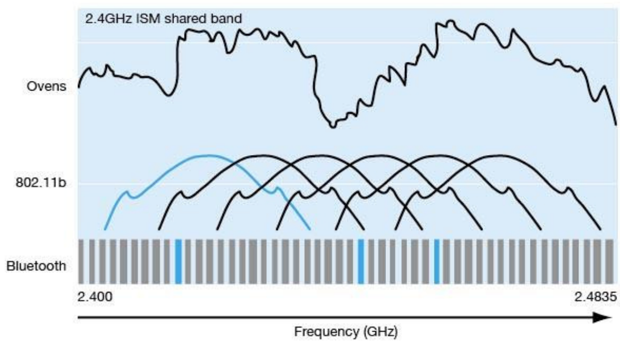

Figure 4: ISM band with interfering technologies

To draw a simple and practical conclusion from the above, we would say: roaming or mobile WLAN users are under the constant influence of Bluetooth and microwaves but not to a severe extent. To be able to better quantify this conclusion, we set up an environment within our traffic measurement tested where we varied the number of users attached to an access point (AP) as well as the distances of the users from the AP. We then exposed the users to Bluetooth and microwave interference sources (both stationary and moving) in either constant or burst mode and with various distances from the access point as shown in Figure 5. We then deduced a generic quantitative impact of those two interference sources after conducting many different trials and capitalizing on the obtained results as shall be seen in the next sections. Figure 5 shows a sample topology with 3 users all impacted but to different extents, depending on their distances from the AP by an external interference source (in this case Bluetooth).

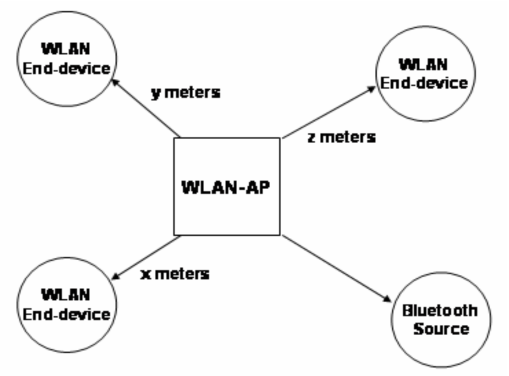

Figure 5: WLAN-Bluetooth interference setup

III. TRAFFIC MEASUREMENT WITHIN THE TESTBED

More access technologies simultaneously implies at the beginning more interference and more network management hurdles. However, as an operator, one has to see everything with a panoramic eye; in other words, the various network access technologies can be set up and configured in such a way that would reduce interference and conflicts.

Some research effort has been spent on defining analytical frameworks for capacity management in wireless networks especially on the downlink path; [15] is such an example. In [15], the authors stress the fact that both radio characteristics as well as overall traffic intensity distribution are very crucial pieces of information which have to be harmonized; this is also the main result and conclusion of their research effort. Compared to our approach, there are many similarities in terms of what information we take into account when modelling our network, namely radio information and traffic behaviour, but the important difference is how we use the information and what conclusions we draw using our approach. We divide the characteristics of the communication channels on the radio part as well as in the core network into two categories: parameters which are to be configured by the operator or user and those that cannot be influenced or configured and are sort of 'dictated' by nature. The former set, we configure in such a way that default and 'best-suited' values are taken based on statistically averaged measurements. The latter set, we take into account for each particular value either measured and statistically averaged numbers or benchmark values set by standardization bodies. Examples for the first category are outlined in tabular form in Table 1.

IEEE 802.11e and WiFi Multimedia Extensions

Particularly important for WLANs is the "to emerge" standard for QoS, namely 802.11e. This standard performs access control to guarantee a certain degree of fairness and achieve some kind of prioritization among traffic classes. The shared medium access scheme is a mixture of polling and contention-based access with the various inter-frame space windows and contention windows to control the process.

The basic way how 802.11e functions is outlined in Figure 6:

Parameter Name	Type	Typical Figure or Pattern
WLAN shared medium access scheme	Configurable	Basic or RTS/CTS (Request to Send/ Clear to Send)
Frequency Selection Scheme	Configurable	DFS (Dynamic Frequency Selection)
Noise and Interference Levels	Non-configurable	[0-very large value] (e.g. 30 or 40 dB) Should be measured each time (no single typical default value)
Access Point Transmit and Receive Power	Configurable	Variable; limited with regulatory bodies Typical: 17dBm
Interference Source Behaviour	Non-configurable	Scattered (multi-burst), Constant, Moving/ Stationary Source

Table 1: configurable and non-configurable parameters

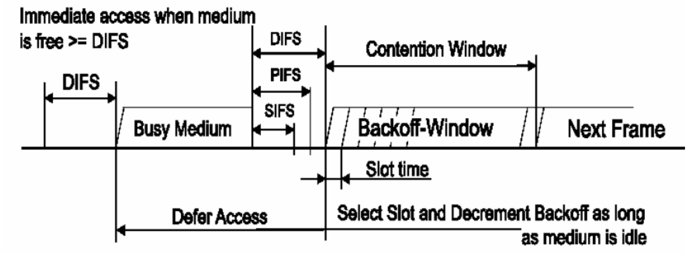

Figure 6: basic 802.11e mechanism

Due to the fact that the IEEE standard 802.11e [19] for quality of service management over WLANs has not yet been finalized, an alternative called WMM (WiFi (Wireless Fidelity) Multimedia Extensions) is currently being used.
Going into the deepest details of how 802.11e functions is out of the scope of this paper, but we would still like to highlight some important terms used in our configuration setup scenarios:

- DIFS: Differential Inter-Frame Space: equivalent to SIFS plus two time slots
- PIFS: Priority Inter-Frame Space: equivalent to SIFS and one additional clock-time slot
- SIFS: Short Inter-Frame Space: shortest time interval between two channel frames
- TXOP: Transmission Opportunity: time interval during which a station has access to the channel (thus blocking other contenders) for transmission; in case frame is too large to be transmitted during a particular TXOP, it has to be truncated and sent over several intervals

Traffic Classes and Traffic Treatment

On the client side, a range of eight traffic classes is defined namely 0 till 7. The 802.11 access points shortly designated as QSTA (Quality of Service Station) supports on the other hand four traffic classes namely: background, best effort, voice and video as seen in Table 2.

Client Class	QSTA Class
1,2	Background
0,3	Best Effort
4,5	Video
6,7	Voice

Table 2: client to access point QoS class mapping

WMM Automatic Recognition of Traffic Classes

With the help of WMM it is possible to prioritize voice packets over data packets. In the absence of appropriate QoS standards for wireless networks, packet loss, jitter, etc can affect voice quality even if the network is not heavily loaded. The 802.11e standard deals with QoS for wireless networks. Wi-Fi Multimedia (WMM) is a component of 802.11e and enables multilevel priority support, admission control, and auto power-save delivery. Multilevel priority support helps to prioritize traffic. Admission control enables the APs to accept or reject calls depending upon their capacity status. Automatic power-save enables a sleep function that allows handsets to wake up in time to receive the voice packets instead of being on power all the time.

Mechanism

Due to the fact that multimedia traffic is the most sensitive to delays and delay variations (jitter), the effects of employing 802.11e or WMM can be best seen on such traffic. For this reason, we thought of the following setup: using a closed-loop protocol such as TCP on ISO/OSI Layer 4 in order to be able to either unicast or multicast large multimedia chunks over e.g. HTTP or FTP (over TCP). The important thing is to use WMM for a sufficiently long interval of time to perceive its benefits or effects in general. We used a self-made (self-coded) MPEG Video file with the size of about 1.4 Giga-Bytes. As seen in Table 3, the TXOP (transmission opportunity, or transmission duration) for the video traffic class was vastly varied within ten experiments the results of which are summarized in Figure 7. The aim was to deduce the pattern followed by system throughput as TXOP is varied.

Tools

For tracing, monitoring, packet capture, and protocol analysis purposes, we used a tool designed specially for WLANs, the name of which we do not want to mention in this paper for obvious reasons. This tool captures packets on the IP level as well as on ISO/OSI layer 4 with detailed TCP and UDP header and payload content recognition. It is possible to detect and sort almost all traffic (up to 99.99%) on the radio interface in the vicinity of the device on which this tool is installed.

Configuration

Access Category	Cont. win Min	Cont. win Max	SIFS	TXOP
Back-Ground *CC: 1,2*	4	10	7	800
Best Effort *CC: 0,3*	4	10	3	1000
Video *CC: 4,5*	3	4	2	***Variable***
Voice *CC: 6,7*	2	3	2	1504

Table 3: WMM configuration for our testbed; CC=client class; all units in microseconds

In addition to the flow treatment settings summarized in Table 3, a lot of other items have to be configured and highlighted in order to have a complete view of the environment where we build a small instance of our operator network. This is outlined below:

- Transmit Power of Access Point: Max (-1... 17 dBm)
- Client Receive Power: Max (same scale)
  - Supported data rates: 6,9, 12, 18, 24, 36, 48, 54 Mbps
  - Variable power control scheme for max. data rate
  - RTS/CTS scheme: on; max # retries (RTS): 64
  - Dynamic Frequency Selection (DFS) scheme enabled; bands enabled: Band1: 5.150-5.250 GHz; 100 MHz channel bands (total: 4)

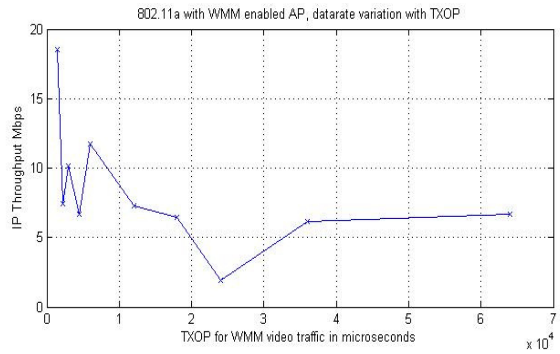

Figure 7: 802.11a with WMM throughput change for fixed payload and increasing TXOP for video traffic

IV. Application Scenarios

A. Network Capacity: Analysis versus Measured Values

ISM Unlicensed Band Inter-technology Interference Analysis

In this respect, we focus on capacity analysis and technical impacts which arise when deploying various collocated access technologies with overlapping frequency bands. One such issue has been extensively studied in [5][18][20]. Our aim however is not to propose alternative mechanisms for interference mitigation between WLAN and Bluetooth as in [5]. We aim at highlighting the setup we came up with in terms of positioning (topology), dynamics (motion), and network parameters in order to approximate as much as possible the most commonly existing real-life situations and then evaluate the measured impacts.

No. of Stations	802.11b Rate Mbps		802.11a Rate Mbps	
	Basic	RTS/ CTS	Basic	RTS/ CTS
1	6.9	5.7	30.2	24.7
2	3.7	3.1	15.7	13.2
3	2.5	2.1	10.4	8.9
4	1.8	1.6	7.7	6.7
5	1.5	1.3	6.0	5.4
6	1.2	1.1	4.9	4.5
7	1.0	0.9	4.2	3.8
8	0.9	0.8	3.6	3.4
9	0.8	0.7	3.2	3.0
10	0.7	0.6	2.8	2.7

Table 4: analytical data rates per WLAN cell for multiple users as derived in [18]

B. 802.11b and 802.11g Interference with Bluetooth

In environments with the IEEE 802.1x protocol for authentication, Bluetooth can be well used as a protocol for connecting the PIN carrier, namely the mobile phone and the end device, namely a PDA or a laptop. In the cellular networks that we use, namely WLAN and UMTS, we assume the authentication process over BT via the mobile phone will be a process often required and constantly accompanying the regular 802.11 b and g traffic; the pattern of Bluetooth usage is not that difficult to analyze, but is out of the scope of this paper.

Based on this information about the usage pattern of Bluetooth in the vicinity of 802.11b and g access points, a substantial set of test cases is required to reflect this behavior. Bluetooth usage can be described as periodic on the large scale with a sporadic or burst-like style. Users using Bluetooth entering their PIN codes and getting access to the network is something periodic and on the other hand some Personal Area Networks (PANs) may be active with a master device managing slaves or some peer-to-peer (P2P) application may be running such as a file transfer via Bluetooth. We therefore generated this Bluetooth activity within our testbed in order to measure to the closest extent possible the impact on the users of the 802.11-based network operator. Combinations of moving and stationary Bluetooth as well as WLAN users were tried out. Now we will go through some observations from the traffic measurement testbed to depict the results.

Throughput Convergence of Multiple Stations due to Bluetooth Interference

Convergence due to Bluetooth is hard to explain mathematically, but is observed multi-fold with experimental setups in the testbed.

Despite the fact that e.g. 3 stations have the same equipment manufacturer for the WLAN cards and were spaced equidistantly from the access point, some stations were able to acquire a significantly higher bandwidth portion than others. On the other hand, one station was left to starve out being able to acquire a very little amount of bandwidth in the range of a few Kbps. As soon as the Bluetooth source is turned on, the IP throughput levels of all stations converge. This observation of the 'convergence' phenomenon was in 80% of the 100 test cases; whereas in the rest the normal situation that all IP throughput levels of all stations dropped to some extent.

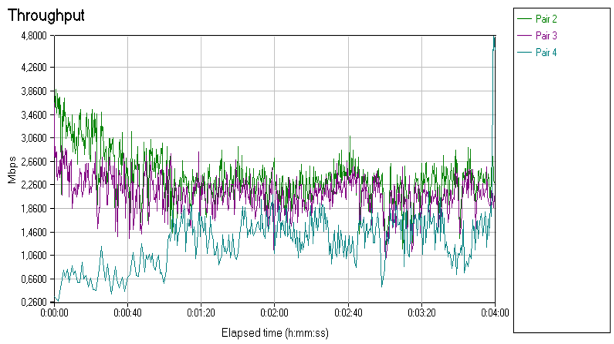

Figure 8: throughput convergence in multi-user environments with BT

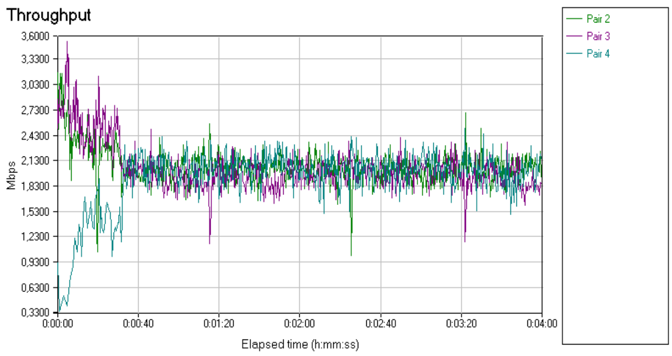

Figure 9: strong throughput convergence case

It is observed that when using trace tools which employ flooding mechanisms, a high variance in the acquired bandwidth under 802.11b RTS/CTS (Request to Send/Clear to Send) appears. In the context of the setup which is very near to real-life situations, we have only a total effective sum of about 6 Mbps for all 3 active nodes; the rest is lost due to interference. If we look at the multiplicative variance, the highest throughput is at the beginning of the setup about 3.3 Mbps corresponding to "Pair 3" in the above figure is higher than the lowest acquired throughput corresponding to "Pair 4" which is 0.33 Mbps by about a factor of 10. This variation is reduced to a negligible factor close to 0 when turning on Bluetooth.

This convergence of effective bandwidth resource amount acquired starts and continues to take shape under the influence of Bluetooth till the end of the test batch.

C. 802.11b and 802.11g Interference with Microwave

As Figure 10 shows, a WLAN access point employing either the 802.11 b or g access technology is able to re-adapt very fast as soon as the source of interference is gone. A microwave oven for instance is a continuous source of interference with almost constant SNR. The drops can be seen graphically and portray the exact times when the interference source was turned on and off. Also it is important to note the slope of the throughput graph whereby the sharper the slope on the upward path, the faster is the WLAN communication in re-adapting.

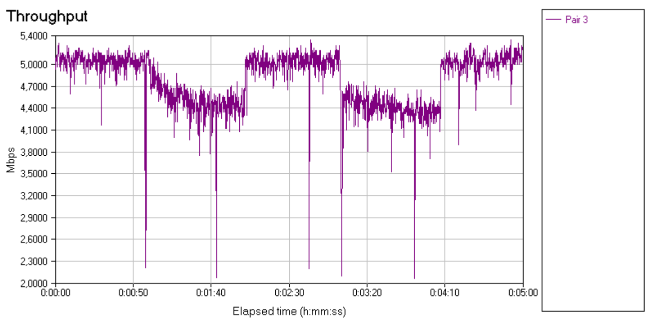

Figure 10: two-interval microwave interference on 802.11b

Figure 11 shows the same case with single interval interference. Conducting many trials with various topologies led us to the conclusion that the most significant factor is the distance from the interference source (e.g. Bluetooth or microwave) to the access point rather than to the individual mobile stations using WLAN. Statistically seen, the damage to the signal of WLAN over 802.11b due to microwave is in the range of 8% up to 30% bandwidth loss; on the average: 15-20%. Considering the fast recovery and short range impact, we conclude that microwave sources do not have to be taken into account when performing network planning.

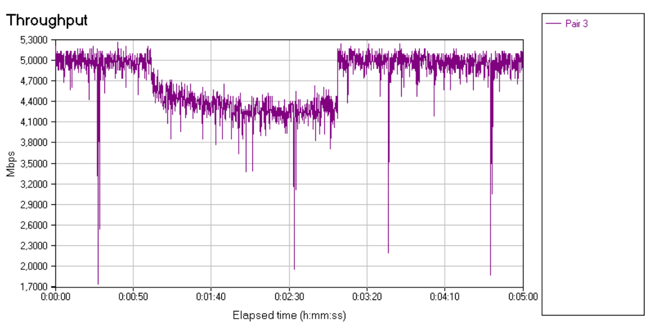

Figure 11: single-interval microwave interference on 802.11b

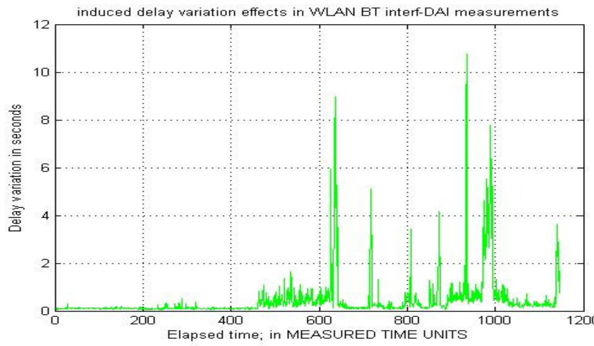

Figure 12: delay variations and increase due to BT interference

Figure 12 shows the sharp increase in cycle times or round-trip times due to Bluetooth interference. WLAN is a particularly delay-sensitive technology which can be easily impacted in this respect. It is particularly hard to assure that multimedia over 802.11 networks can function properly and at the same time not waste substantial portions of the overall radio resources. It has been observed in our traffic measurement testbed that at the deep fades of throughputs, delay peaks occur; so this is an inversely proportional relationship between those 2 complementary parameters. The scales for the parameters are almost linear; in other words, measurements show that when the bandwidth drops by e.g. 60%, the delay increases by a proportional factor. Of course some fine tuning of this formulation would help, adding some coefficients and variables.

D. Projection for the Network Deployment Process

It is possible to mathematically calculate, e.g. the theoretical capacity a station would get in any finite sized network, even as large as the target network to be deployed. Moreover, performing measurements in a network up to certain number can then enable network engineers to perform induction or interpolation on the pattern embodied in the value vector with real measurements.

As seen in Figure 13, we illustrate exemplarily the approach of this paper for network planning. In this case, the critical parameter in network planning is the effective throughput a station gets. On a single access point, up to seven clients were installed and their capacities were measured (red curve). Analytically, using capacity formulae, the effective data rate a station would be able to achieve in a particular cell was also calculated as in Table 4 (blue curve in the figure). Upon interpolating or performing induction on the red curve (measured values), the black dotted line is obtained. Interpolation or induction is done for a network size which is larger than a testbed can accommodate. Finally, the solid back curve with the asterisk marks is obtained by finding the midway curve between the dotted black and the blue one. This resulting curve is then the one used for network planning. This is how the gap is bridged between measurements and analytical calculations.

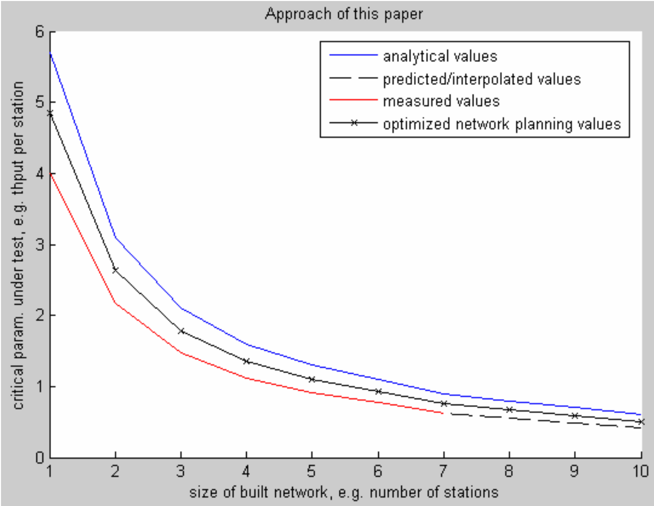

Figure 13: Interpolation and induction approach for 'gap-bridging' of the distance between analytical and real work for network planning

V. CONCLUSION

We have presented several issues that any operator has to take care of; from interference, to coverage and capacity planning to large scale deployment and consistency in terms of subscriber support. The most significant aspect of a testbed is how to quantitatively tackle the mentioned issues to determine their severity or set benchmarks or statistically averaged values for them, and this is exactly what we do. The eventual goal is to perform network planning based on measurements for a smaller scale network or sub-part and then performing extrapolation. The extrapolated values corresponding to a network larger than the size of the testbed are then averaged with theoretically calculated values to achieve even more exact results.

VI. FURTHER WORK

Since this work is part of a larger scope, we are constantly working on extending the concept presented here. Mainly, this work has been inspired and also conducted within the scope of the EU FP6 Project OBAN (Open Broadband Access Network) [11]. The vision of OBAN is currently being pursued. At the end, an operator which consists mainly of WLAN networks in the front-end shall optimally allocate capacity to mobile roaming users in such a way that this virtual operator really proves to be effective in being able to meet customer resource and QoS needs, harmonize with other deployed networks and transmitters in the same frequency bands, and also balance the issues of coverage and capacity dynamically, coping with the network context. Coverage versus capacity is a significant tradeoff; moreover being a virtual operator (OBAN) deployed mainly but not exclusively over existing networks, makes the situation more complex. We are constantly working on refining the concept presented in this paper which deals with bridging the gap between analytical work and real values. The paradigm used will remain the same, but more parameters will be incorporated into the model.

VII. ACKNOWLEDGEMENTS

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