Combining performance monitoring and location data in wireless networks*

Laurent Paquereau[1,2], Brynjar Viken[1], Poul Heegaard[1,3]

[1] Telenor R&D, Trondheim, Norway
[2] Centre for Quantifiable Quality of Service in Communication Systems**, Norwegian University of Science and Technology, Trondheim, Norway
[3] Department of Telematics, Norwegian University of Science and Technology, Trondheim, Norway

Abstract

This paper focuses on investigation of methods for WLAN monitoring, and in particular how measurements and monitoring of wireless networks can benefit from user or terminal location data. By combining passive network monitoring data (trace based) with user or terminal location, quality measures such as coverage and quality maps can be generated.

Compared to wired networks, management and monitoring of WLANs have additional challenges because the performance is heavily dependent on variable and unpredictable characteristics of the physical media (i.e. the air link). Consequently, there is an increasing need to understand how wireless technology will affect network management, troubleshooting and performance monitoring.

1 Background

Wireless network technology has experienced a tremendous success and the market is rapidly growing. Wireless local area networks (WLAN) technology (IEEE 802.11x) is in widespread and increasing use e.g. for large enterprises, "hot-spot", and home networks (see [1] for a survey of WLAN networking). In particular WLANs have become popular with 802.11b (WiFi). For wider range (typically outdoor use), e.g. for interconnection of "hot-spots", WiMax (IEEE 802.16) technology with long range and high capacity coverage is coming. In this paper we mainly focus on the WLAN domain. Some of the main reasons behind this success are the ease of integration with existing infrastructure and the simplicity and low cost compared to wired network infrastructures. Currently, it is not only used for its original purpose, to connect computers in a local area network, but also for applications that have real-time requirements such as IP telephony.

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Compared to wired networks, management and monitoring of WLANs have additional challenges because the performance is heavily dependent on variable and unpredictable characteristics of the physical media (i.e. the air link). Consequently, there is an increasing need to understand how wireless technology will affect network management, troubleshooting and performance monitoring.

In this paper a brief overview of WLAN (IEEE 802.11) and location technology is first given in Section 2, followed by a discussion of how to combine performance monitoring of wireless network and user and terminal locations in Section 3. Section 4 presents *WLAM (WLAN Location Assisted Monitor)*, a prototype for low-cost flexible passive measurement in WLANs. Finally, some closing remarks are given in Section 5.

2 WLAN and location technology

In order to understand the context of the measurement methods described in this paper, the key architecture and functionality of WLAN (based on 802.11 standards [2]) and location technology are given. More comprehensive presentation of the standards can be found in e.g. [3].

WLAN architecture is cellular and each cell is called Basic Services Set (BSS). The components that connect to the wireless medium are stations (STAs). WLANs are configured either in ad-hoc, no coordinating station, or infrastructure mode, with an access point as coordinating point and access to other subnets, see Figure 2.

The MAC layer provides reliable delivery mechanisms for the IP layer over noisy and unreliable wireless media and ensures fair access probability to the medium in terms of throughput. All the stations contend for access to the medium using Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) algorithm.

With the increasing use of various wireless technologies, the need for context and location based services has become obvious. Todays applications like traffic updates, weather reports, street-by-street navigation, personal advertising, museum guiding, finding a doctor in a hospital, are based on the handset location. Emergency and personal safety have been driving forces for these applications. More advanced applications can even be built if indoor and outdoor positioning can be provided. Current practice for indoor WLAN positioning is to determine the location by measurement of time of arrival of frames sent on the wireless medium, or the signal strength (see [4] for details). The latter is applicable for location determination if the transmitting power is constant or known, and can be measured from e.g. beacon frames sent frequently by each access point.

3 WLAN performance and location data

There are two principal methods to collect performance measurements; either actively by insertion of probe packets or passively by observing real packets. These fundamental measurement strategies are denoted *active* and *passive measurements*, respectively [5]. The measurements can be performed at different protocol layers (link, network, transport and application layers), as illustrated in Figure 1. This section focuses on current practice of passive measurement in wireless networks and outlines ideas for combining this with location data. Although the specific details are limited to 802.11, the measurement techniques and challenges described are generally also applicable to other wireless technologies such as WiMax.

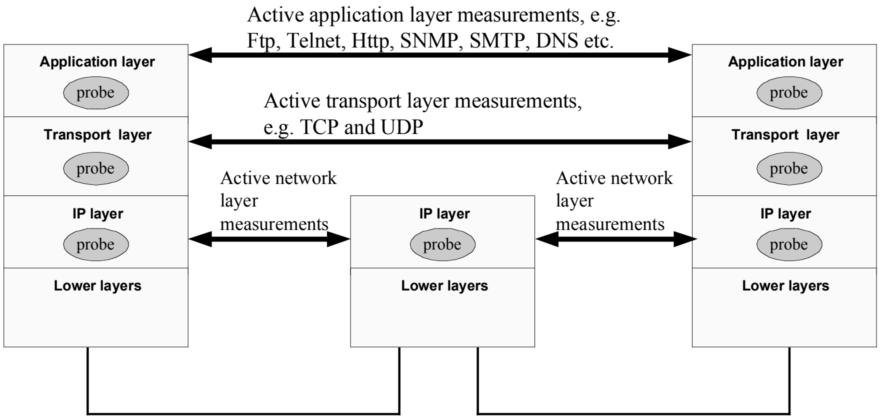

Figure 1: Active and passive network measurements at different protocol layers

3.1 Current WLAN monitoring practice

A number of measurement studies have previously been done [6]. Most of these investigations have been conducted on the wired subnet. In [7] it is argued that wireless measurements are more appropriate to capture the wireless medium characteristics and their impact on the traffic pattern. Wireless measurements allow to capture more detailed information about the wireless media than if the measurements are carried out on the wired subnet. It is stated that wireless monitoring can efficiently identify the causes of end-to-end losses and delays. In [8] a study of how slow user motion influences the wireless link quality is presented. In contrast to common assumption the experiments show that an increase of motion speed can result in a better link quality; the packet loss rate and variance, measured after link-layer retransmission, decreases. The measurements also show that link quality is predominantly influenced by the modulation type, the maximal number of retransmissions, the experimental setting, and even the quality of power supply. In [9] network planning is addressed as a new application area for mobile location technology. In particular, location techniques in UMTS and their capability to support network planning are evaluated. Knowing the received signal level as a function of location is a key issue in network planning. The signal level is used for coverage planning, interference analysis and neighbour planning. Considerable cost savings can be achieved if dedicated field measurements can be replaced by measurement reports provided by standard mobile phones. The paper addresses the accuracy of signal level probing. The Adaptive Coverage System (ACS) from the IST-CELLO project is presented in [10] and [11]. This is a solution to locate the area in cellular networks where more capacity is needed and making relevant changes in the network configuration. The concept consists in utilizing location information for adaptively adjusting antennas in order to achieve an increased network capacity and stability.

To the best of our knowledge, extensive work on how user location in wireless LAN can be utilized to improve wireless network measurements has not been presented so far. This is the focus of this paper. By combining passive network monitoring data (trace based) with user location, quality measures such as coverage and quality maps can be generated.

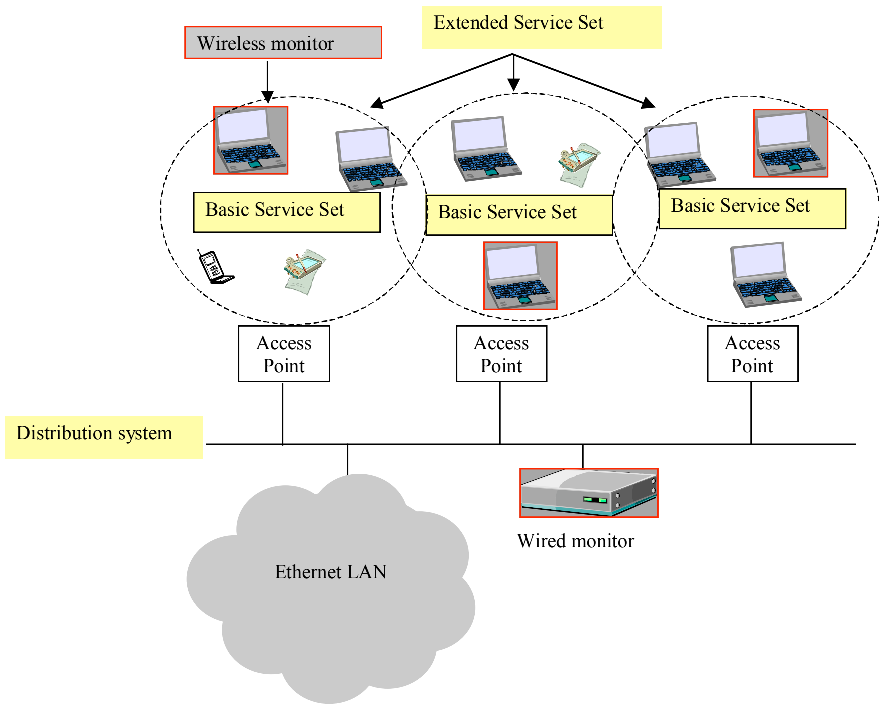

Figure 2: Passive measurement instrumentation in 802.11 infrastructure network.

3.2 Challenges of passive measurements in WLAN

This section discusses challenges that are particular for passive measurements of WLANs. A passive measurement probe can be located at the wired or wireless subnets, as illustrated in Figure 2. Passive measurements in both the wired and wireless portion of the network can be used without disturbing the actual user traffic carried [7].

Passive measurements in wired subnet can be collected by dedicated monitoring equipment or by functionality integrated into hubs, switches and routers. A wired monitor is able to capture packets in the network infrastructure that connects the more access points (AP). An obvious disadvantage is that such a monitor cannot observe the actual IEEE 802.11 frames sent on the air link in the wireless subnet. Thus, it is less suited to observe the wireless medium properties.

Monitoring in the wireless subnet can be done by data collection in dedicated monitors, or by integrated monitoring functionality in the WLAN interface of the access point. A wireless monitor is able to capture frames, including link layer headers, sent between the access point and mobile nodes. And it is possible to fetch physical information from the wireless interface, such as signal strength and noise levels measured by the card. The physical and link layer headers captured by a wireless monitor are more appropriate to analyse the wireless medium characteristics. However, this approach is significantly more challenging than monitoring in the wired subnet. The *hidden node* problem must considered, i.e. the monitor may be out of range of a station and then fails in capturing the communication between this station and the AP, or the monitor may capture traffic sent by a station that is out of the AP's range. Furthermore, passive measurements in wireless networks must deal with changing radio coverage and unreliable physical medium that strongly influence the quality and relevance of the collected measurement data. In [7] frame losses in the passive monitor (*monitoring losses*) are identified to be the major problem of wireless packet capturing, including:

- Type loss: the monitor is unable to capture specific types of packet (e.g. some WLAN interface card is unable to capture ACK frames)
- AP loss: the monitor does not capture nearly all the frames generated from specific APs
- Generic loss: monitor fails to capture frames for other reasons.

3.3 WLAN performance parameters

This section focuses on parameters measured by one or more monitors in a wireless subnet. Performance parameters on both MAC and IP layers can be observed and are of interest in order to estimate the quality of the transport service provided by the wireless network. In the following, the performance parameters for a *frame* are listed, where a frame is an entity that can be either a MAC frame, an IP packet, or a transport layer (e.g. TCP, UDP, RTP) packet.

Frame losses and loss variation. A frame is said to be lost if it has been sent but not received by its destination on the wireless medium. A lower bound for frame losses can be estimated based on sequence number and the retry flag carried in MAC headers, and ACK corresponding frames observed by the wireless monitor. At TCP/IP layer losses can be detected by capturing the transport header sequence number and the TCP ACK packets. Note that frame losses must not be mistaken for monitoring losses where the frames have actually been transmitted successfully.

Frame delay and delay variation. It is possible to monitor the round-trip time (RTT) and the one-way delay by processing frames captured in the wireless medium. In [12] an algorithm is developed for estimation of the RTT by passive measurement of the TCP packets. The time of observation for a frame sent on the medium depends on the actual physical location of the passive monitor.

Link load and throughput. Type of transmitted frames (data, control, and management) can be easily studied based on the MAC header. Traffic volume in frames and bytes can also be measured.

Number of MAC layer retransmissions. Based on the retry bit and the sequence number in the MAC header, number of retransmissions per sequence number can be given.

Signal strength. Distance from the signal source and interference from intervening objects or other signals degrades the signal reception. WLANs use unlicensed spectrum and the operator must cope with multiple sources of interference. Measurements of signal strength give an indication of the data rates that can be achieved on the medium. Signal strength is measured as observed by the interface of the passive monitor.

It is also interesting to see how the wireless channel (signal noise ratio) relates to and impacts the performance observed at different protocol layers (MAC, IP, TCP/UDP), e.g. how the TCP throughput is affected by variation in the IP throughput, which again is affected by variations in the MAC frame performance parameters and the signal/noise ratio.

3.4 Combining WLAN performance and location data

The best practice WLAN planning, installation, optimization or monitoring, is to only use signal strength values similarly to what is done for GSM networks. Based on the collected data e.g. moving around with WLAN capable devices equipped with GPS[1] receivers, signal coverage maps are built. If the signal is found to be too low in some region, the usual solution is to buy and set up an additional access point. This is based on the generally accepted idea that the addition of a new access point will enhance the overall signal coverage and thus the overall transmission quality and performances (in terms of accessibility, throughput, delay and frame losses). Beyond the significant cost of such an approach, the assertion seems too restrictive, and, as a result, even worse quality and performances may be obtained:

- The addition of an access point significantly increases the traffic (beacon, probe frames) and therefore the potential interferences over the wireless medium.
- Additional access points will increase the number of handovers, which may degrade the performance experienced by mobile end-users.
- Virtual sensing mechanism has effects on all the overlapping BSS (transmitting on the same channel), thus accessibility is not necessarily improved.
- Low signal level may be due to too many reflections and in this case adding an access point will not help.

Hence, it is much more challenging to estimate quality experienced for a WLAN, especially indoors e.g. in a hospital or an airport (hotspots), than for a GSM network where signal level is mostly sufficient.

An intuition is that it must exist an optimal infrastructure in terms of numbers of access points needed and location of these access points to get the maximal quality. Advanced wireless measurements are required to determine this (near) optimal infrastructure. To the best of our knowledge, there is no tool available today that intends to provide extended monitoring features and measurements for WLAN.

Monitoring the network under normal operation seems to be the only way to evaluate the actual performances experienced. Simulations are an alternative but will face great challenge in coping with the complexity as mentioned. The idea is that by combining WLAN passive, trace based, network monitoring data with location data, coverage and quality maps can be generated. The positioning functionality should be integrated in the access point so that the terminal does not need any special equipment. Network monitoring (e.g. generation of quality coverage maps), planning and dimensioning (e.g. coverage planning, interference analysis and neighbour planning) will benefit from the combination of location data and WLAN measurements.

[1] Global Positioning System

4 WLAM: WLAN Location Assisted Monitor

This section presents WLAM (WLAN Location Assisted Monitor), the prototype of a tool we have developed for combining passive measurements and location data. A number of free open-source tools are available for WLAN passive monitoring and troubleshooting (frame capture and analysis), ranging from widely used tools, e.g ethereal[2] or tcpdump[3], to very specific WLAN monitoring applications, e.g. kismet[4] or airtraf[5], (see [13] for details). However most of these latter tools have been developed with wardriving purpose in mind. Wardriving means driving around with a laptop with a wireless card and an antenna looking for accessible wireless networks. None intends to provide extended statistics such as frame losses or quality measurements not solely based on the received signal strength. Besides, the use of GPS data is also restricted to wardriving purposes e.g. locating access points in the surveyed area.

4.1 Description of the prototype

The prototype is a flexible and modular tool written in C for Linux for wireless passive monitoring. WLAM supports both real-time monitoring, using a standard WLAN network interface card or an access point with embedded positioning functionality such as the Radionor's RadioEye to capture raw 802.11 traffic, and offline analysis of WLAN frame traces. More precisely supported input sources are:

- Intersil Prism II card in receive-only mode (reference monitor mode) for real-time monitoring (location data is not available)
- Radionor[6] Cordis RadioEye (CRE) device for real-time monitoring. RadioEye is a hardware based sensor capable of accurately determine the physical location of a transmitting station on the wireless medium.
- Pcap file for offline monitoring or replay (available data depend on the original source used for capture, Prism II card, RadioEye or another interface, using WLAM or another tool for capture e.g. tcpdump)

The tool aims to provide information and statistics (see Section 4.3) about the current traffic over a specified cell and the stations transmitting. Statistics and traffic are displayed in a console screen. Using available options, WLAM can also display graphs and/or maps in real-time (see Section 4.4) and write a log file and/or a PCAP file that contains the captured traffic. The latter can be read by WLAM as well as by any other external tool supporting PCAP files.

4.2 Design of the prototype

Figure 3 illustrates the design of WLAM (see [14] for details). The objective is to provide a modular and flexible but also efficient tool to perform real-time processing.

[2]http://www.ethereal.com
[3]http://www.tcpdump.org
[4]http://www.kismetwireless.net
[5]http://www.elixar.com/corporate/history/airtraf-1.0/
[6]http://www.radionor.com

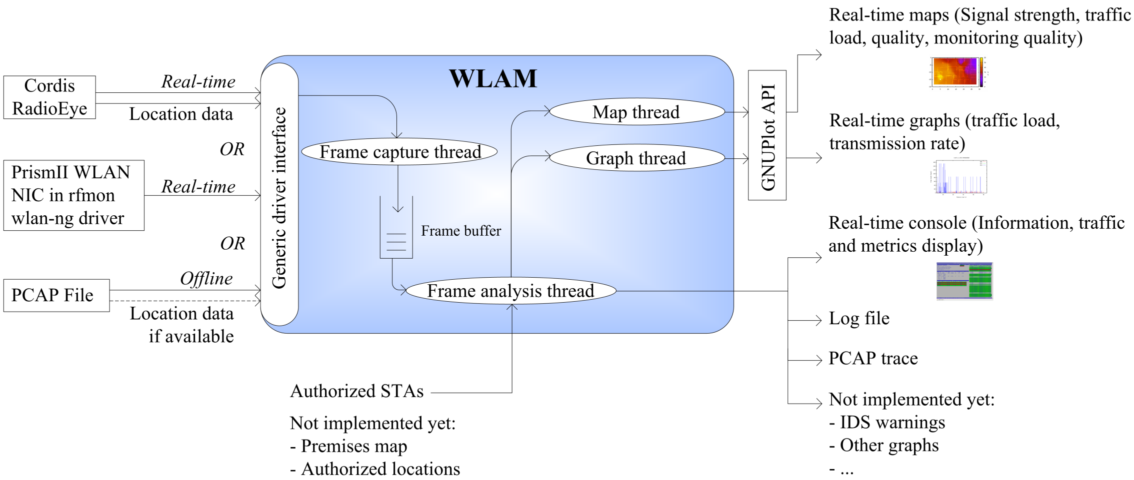

Figure 3: WLAM overview

Modularity and efficiency are addressed by the mean of threads. There are at most four threads running in parallel; namely a *frame capture thread*, a *frame analysis thread*, a *graph thread* and a *map thread*. The graph and map threads are only created on-demand according to the options specified by the user at runtime. The frame capture thread interacts with the driver to get frames one by one. To ease the support of various types of hardwares/drivers, the driver is not accessed directly but through a generic driver interface. Each captured frame is then recorded as it is, without any filtering or parsing, in a FIFO buffer (*frame buffer*). This is to minimize the operations in order to minimize the number of frames the monitoring unit fails to capture. The frame analysis thread takes frames one by one from the frame buffer and processes them. That is it retrieves both endogenous, i.e. derived from the frame itself, and exogenous, e.g. arrival time, signal level and sender location if available, attributes from the record, updates global, per-sender and per-link (station - access point) metrics and refreshes the display screen. If required the frame is written in a PCAP file. WLAM adds its own header to the frame to save exogenous attributes and in particular the location information. The purpose of the graph and map threads is to periodically refresh graphs and maps respectively if displayed.

Flexibility is provided by different possible options that allow the user to fine tune the configuration of the program at runtime according to its needs and hardware. For a list of available options, the reader should refer to [14].

4.3 WLAM console and metrics

The captured frames and the metrics are displayed in real-time in a console screen (Figure 4). The screen is divided in five parts:

Config gives a summary of the configuration parameters.

Other BSSs contains a list of the overlapping BSS detected.

Traffic shows the frames captured on the monitored cell. The display is refreshed every second and only the most recent traffic is shown. For each frame the following information is given: the relative arrival time, the source and

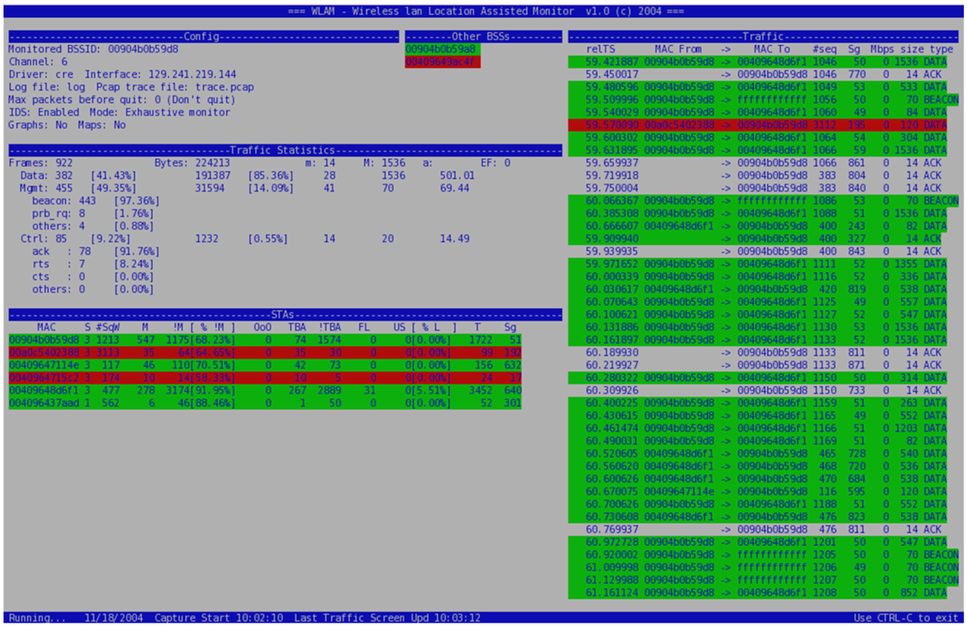

Figure 4: WLAM console screen

destination MAC addresses, the frame sequence number, size and type, the transmission rate and the signal strength measured by the monitor.

Traffic statistics presents the numbers of captured frames and bytes as well as minimum, maximum and average values of the frame length. Per frame type and subtype details are given. This part is updated after each frame capture.

Stations provides per station information and metrics about all the detected stations on the monitored BSS. It is partly refreshed after each frame capture. Information and metrics are among others: the address and status (not authenticated/authenticated/associated/associated to another BSS) of the station, the number of monitored frames and the total number of frames transmitted (based on the sequence number analysis) between the station and the access point in order to assess the monitoring quality, the number of retransmitted frames, i.e. lost frames, and the frame loss percentage in order to estimate the communication quality, and the mean signal level monitored for frames sent by this station.

Based on a static list of authorized MAC addresses, traffic and detected stations can be colored if the corresponding option has been specified at runtime.

Relevancy of the metrics depends on the monitoring quality. An inherent problem when dealing with wireless monitoring is that one can neither ensure that all the monitored frames are actually received by the destination on the wireless medium nor that all transmitted frames have been successfully captured by the monitor. Frames captured highly depend on the location of the monitor. The standard itself also prevents accurate estimations; a flag in the MAC header indicates if the frame is retransmitted or not but it does not tell how many times it has already been retransmitted. When location is moreover to be computed by the monitoring device, a tradeoff must be made between exhaustiveness of the capture and accuracy of the sender location estimation.

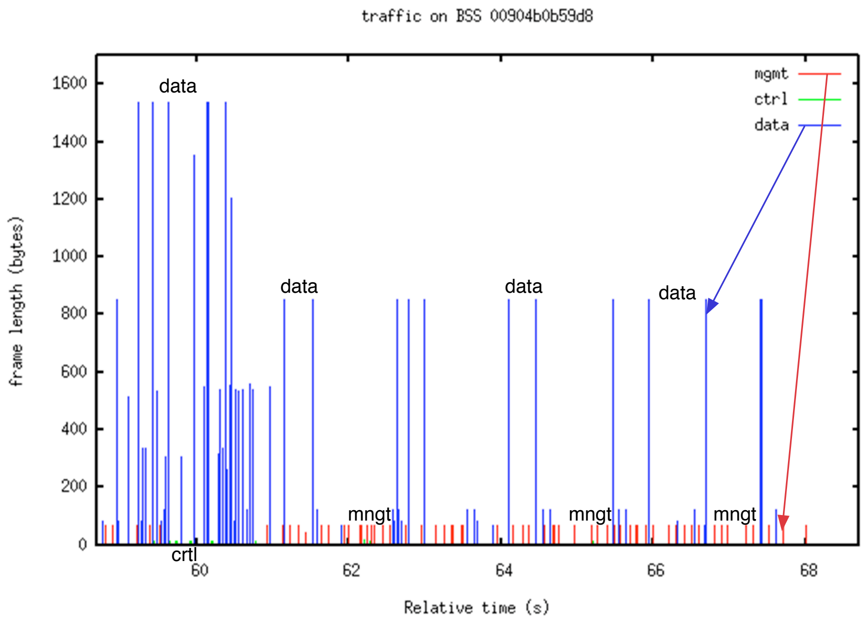

Figure 5: WLAM traffic load graph

4.4 Visualizations using GNUPlot

Using available options, WLAM can display graphs and/or maps using GNUPlot[7] (Figures 5 and 6). More screenshots are provided in [14].

Graphs Two graphs can be displayed. A *traffic load graph* shows in real-time the ongoing traffic on the monitored BSS (Figure 5). Each frame is represented by a pulse which height corresponds to the frame length. Colors are used to differentiate frames according to their type (data, control or management). A *Transmission rate graph* displays in real-time the observed transmission rate of the frames on the monitored BSS. Each frame is represented by a pulse which height corresponds to the data rate.

Maps Four maps can be displayed if the location information is available. A *signal strength map* shows the mean signal level observed by the monitor for each transmitting station at a specific location. A *traffic load map* shows the monitored traffic level (in percentage of the total traffic monitored) between a station at a specific location and the access point. An example is shown in Figure 6. In this case only three stations have been detected by the monitor and the station right under the monitor was transmitting much more than the others. A *quality map* shows the estimated quality of the link (ratio of the number of frames received to the number of frames sent) between a station at a specific location and the access point. A *monitoring quality map* shows the monitoring quality of the link (ratio of the number of frames monitored to estimated number of frames actually transmitted) between a station at a specific location and the access point. For all maps, values of interest for a station or the link between a station and the access point are displayed at the

[7]http://www.gnuplot.org

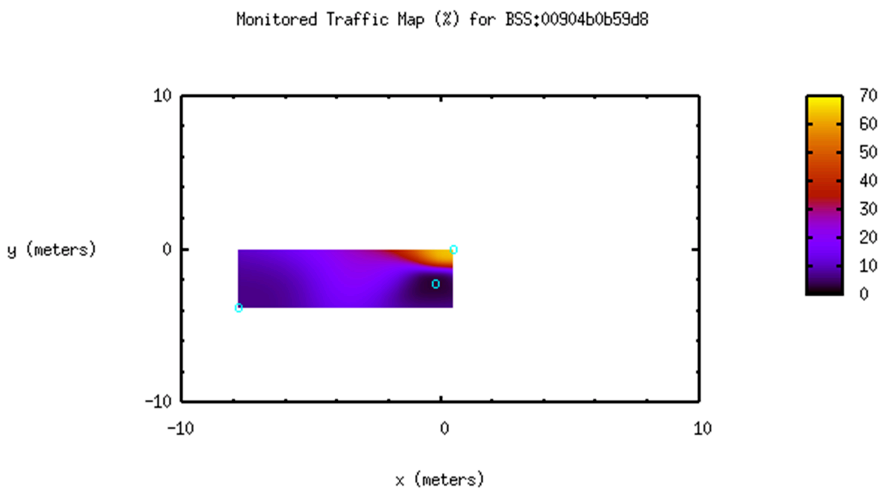

Figure 6: WLAM traffic load map

location of the station. Location values are relative to the monitor location (origin of the map).

5 Conclusion

Wireless LAN technology has experienced a tremendous success and the market is rapidly growing. Some of the main reasons behind this success are the ease of integration with existing infrastructure and the simplicity and low cost compared to wired network infrastructures. Currently, it is not only used for its original purpose, to connect computers in a local area network, but also for applications that have real-time requirements such as WLAN phones.

To provide proper service quality to end-users it is vital to identify problems rapidly such that degradation of end-user services is minimal. At the same time, to ensure a high utilization of network resources, it is essential to have a cost-efficient planning and dimensioning of WLAN networks; i.e. increase capacities and number of access point at the right point in time. In particular, introducing real-time services in WLANs makes it vital to be able to monitor and dimension wireless networks successfully.

Compared to wired networks, management and monitoring of WLANs have additional challenges because the performance is heavily dependent on variable and unpredictable characteristics of the physical media (i.e. the air link). Consequently, there is an increasing need to understand how wireless technology will affect network management, troubleshooting and performance monitoring. This paper investigated methods for WLAN monitoring, and in particular how measurements and monitoring of wireless networks can benefit from user location data.

Further work includes improving the performance of the measurement equipment and extending the functionality of WLAM to provide support for intrusion detection and more advanced performance metrics (e.g. delay) and statistics (e.g. max, min, standard deviation).

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