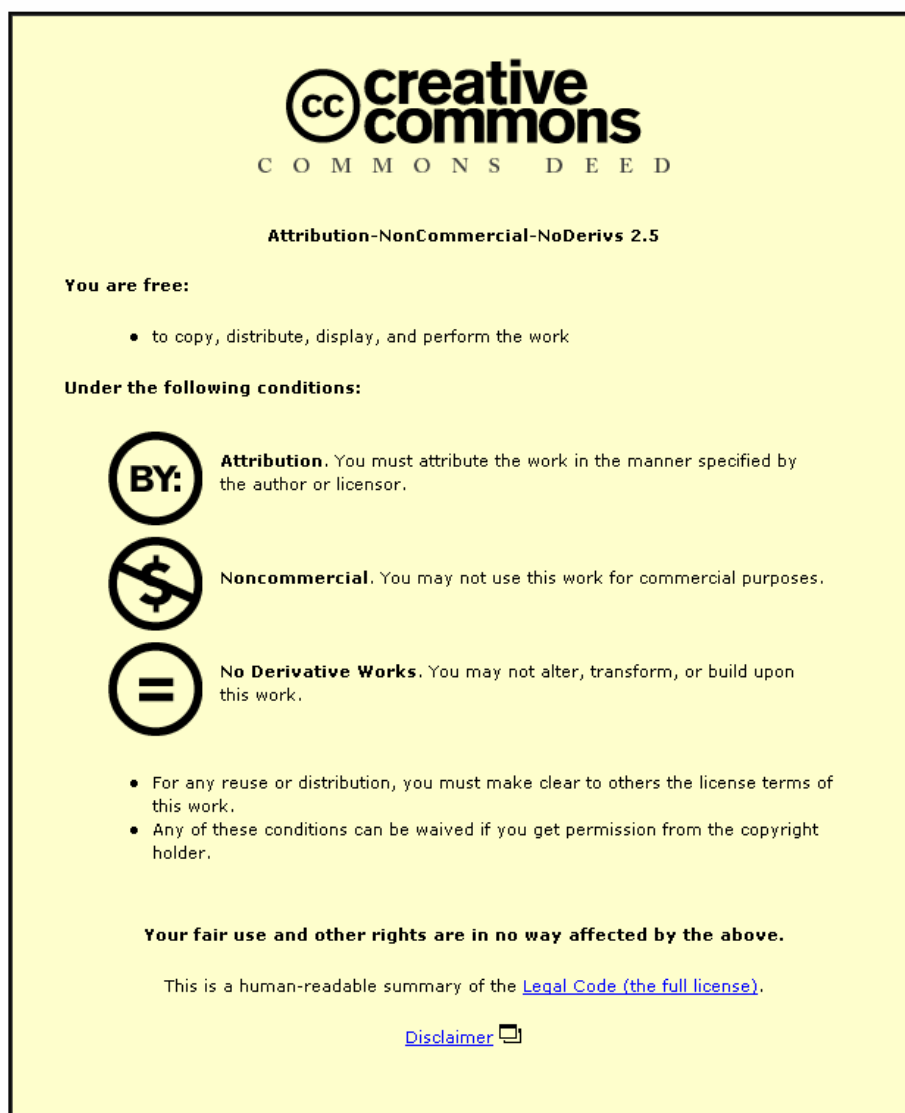This item was submitted to Loughborough's Institutional Repository by the author and is made available under the following Creative Commons Licence conditions.

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A Framework for Cross-layer Measurement of 3G and Wi-Fi Combined Networks

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Abstract--3G networks and Wi-Fi networks could complement each other as each has different advantages of coverage and access capacity. A combined 3G and Wi-Fi network is one part of a heterogeneous IP network which has ubiquitous access capacity. However, the characteristics of the lower layers in the wireless network portion of such a heterogeneous IP network could significantly affect the performance of higher layers, and further, the overall performance of the whole network. A single-layer approach to performance analysis could not provide enough information to present the correlation between lower and higher layers. A cross-layer measurement approach for combined 3G and Wi-Fi network is presented which aims to correlate the characteristics of the physical layer (e.g. channel power and signal-to-interference ratio) to key parameters of higher layer (e.g. packet-loss ratio, and round trip time).

Index terms – cross layer measurement, combined 3G and Wi-Fi network

I. INTRODUCTION

Ubiquitous access to remote information storage and computing services is a trend of current telecommunications and computer networks. Heterogeneous IP networks with wireless access networks is believed to be a way to achieve that. However, each wireless access technology has different coverage and access capacity. It will be necessary to combine those wireless networks, which would allow each to offer higher quality services under disparate conditions and make them complement each other. The most attractive solution for such consideration is to utilize IEEE 802.11 WLAN (Wi-Fi) with high bandwidth in some places where it is available and UMTS (3G) with lower bandwidth where there is no WLAN coverage. Users could get benefit from connecting to the WLAN at low cost and with high bandwidth in the home, airport, hotel, or shopping mall, and connecting to UMTS (3G) with better voice communication services quality at the same time. Integrating Wi-Fi and 3G networks may increase deployment costs, complicate the business/service model and

many adjustments will be required within mobile firms. However, those higher coordination costs do not seem likely to be overly substantial.

In the ISO/OSI network model, overall performance is related to the functionalities of protocols in all layers. In particular, comparing to wired networks, the performance of wireless networks more depends on the traffic characteristics, such as modulation schemes, framing procedures, at the data link layer and, channel power, signal-inference power ratio (SIR) at the physical layer.

Wireless network cross-layer protocol optimisation seems to be a fast growing research area recently. The signal degradation in wireless access networks could significantly affect the reliability of higher layer protocols, and further, the overall performance of a wireless or hybrid communication network which combines wireless and wired networks.

A clear and proper understanding of the performance of the protocols in the physical and data link layer is a premise to implement efficient methods for the allocation of network resources and applications over wireless network. However, only having the characterises of data traffic at the physical layer and data link layer, would not indicate the effect of the higher layer protocol performance parameters, such as the packet loss ratio, round trip time, throughput, and application usability. Dually, the overall performance assessment from evaluating higher layer parameters also could not provide exact information regarding performance degradation due to problems of the physical layer.

Therefore, cross-layer measurement is needed instead of a single layer measurement approach in wireless networks or hybrid networks in order to understand which measures of the lower layers affect higher layer performance and the overall network performance. This is particularly true for coexistence issues in WLAN networks [8] and TCP issues in wireless network [5]. Also, wireless monitoring could take advantage of cross-layer measurement for traffic analysis, user mobility and handoff analysis, and MAC/PHY anomaly detection [3].

Cross-layer measurement means gaining knowledge of different layers, not necessarily all, but generally including

the transport layer, data link layer and physical layer, at the same time. Analysis is carried out in order to correlate the measures representing characteristic of the physical layer and data link layer which impact on the higher layer performance. In other words, it intends to understand the performance of one of network layer as a function of another, or several other layers.

II. RELATED WORK

There are several studies based on cross-layer measurement approaches for wireless networks. In [1], DQoS is presented as a tool for measuring and analyzing CDMA data services, which collects data traces in a cross-layer fashion. Graphical plots are produced based on these synchronized data traces to illustrate throughput, latencies, protocol behaviour and bad events. It could give us a comprehensive view of the connection performance in an end-to-end and multilayer way. Also, DQoS does not require any instrumentation internally in the network, which is extremely difficult to obtain from deployed commercial networks. Authors in [5], utilize cross-layer measurement to characterize RF layer traffic and TCP/UDP behaviour. Based on that, they claim that variable channel rate has a larger impact on TCP behaviour than the RLP (Radio Link Protocol) layer. Also, they present a correlation measure, Normalized Mutual Information, to quantify the impact of lower layer to higher layer.

There is literature relating to cross layer measurement in Wi-Fi networks. In [3], [6], cross-layer measurement is utilized to characterize the PHY/MAC layers of the IEEE 802.11protocol, and correlate these with the user's activities. The Prism2 monitor header generated by the firmware of the receiving wireless card is captured for collecting PHY layer information. This header includes useful information, such as MAC time, RSSI (Received Signal Strength Indication), etc. The characterization from cross-layer measurement helps identify various anomalies in the protocols and security of the IEEE 802.11 WLAN. Authors in [2], [4], [7], investigate interference issues in IEEE 802.11 WLAN through cross-layer measurement. One of the features is that a spectrum analyzer is utilized to measure channel power. As claimed in [2], using a spectrum analyzer has a disadvantage which is measurement time grows inversely with packet transmission rate. However there may be benefits from using a spectrum analyzer.

DVB-T system performance is analyzed through investigating three indices, which are MER (Modulation Error Ratio), power intensity at the receiver connector and video quality metric (VQM), at different layers in [9]. The quality perceived by the end user is considered for estimating the performance of a DVB-T system.

However, the studies above are focused on single wireless network. None of them has done any work in the characteristics of heterogeneous networks using a cross-layer measurement approach.

In this paper, we focus on measuring the performance of a hybrid network which combines 3G and Wi-Fi elements. A cross-layer approach is proposed in order to investigate the characteristics of the lower layers in the 3G and Wi-Fi networks and the higher layer behaviour in such a combined network. The correlation of major physical layer measures to the key values of the higher layers is considered. Because of the differences between 3G and Wi-Fi networks at the physical and data link layers, the measures representing each layer are different. For example, with regards to the physical layer, Signal-to-noise ratio (SNR), which represents the channel condition in Wi-Fi, is measured, instead of Ec/Io in the 3G network. Ec is the pilot strength, and Io is the overall inference [5].

A Framework for collecting measurement synchronously at different layers is also required. We would conduct active measurement in a combined 3G and Wi-Fi network, and characterize the behaviour of the lower layers, such as channel condition, and performance of higher layer, such as TCP, based on the data collected from the framework we present.

III. COMBINED NETWORK STRUCTURE

As show in Figure 1, a laptop is used to connect to the commercial 3G network through a 3G CDMA terminal, which could be a PCMCIA card or a 3G CDMA phone. This laptop uses a wireless adapter to communicate with a Wi-Fi WLAN, which connects with the Internet. Different types of applications would be run on both the laptop and a server to generate different traffic types, such as stream traffic, interactive traffic, voice traffic, data traffic, etc.

The server could be a machine existing in the Internet or a machine in a laboratory which is accessed through the Internet. If the sever is a laboratory machine, we can have control over the non-wireless portion of the heterogeneous network when we measure the end-to-end connection.
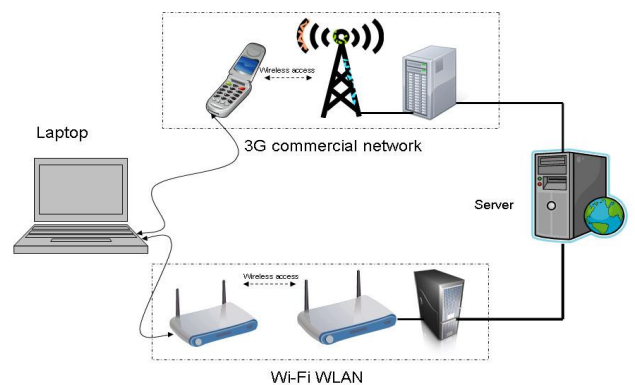

Fig.1 Combined 3G and Wi-Fi network structure
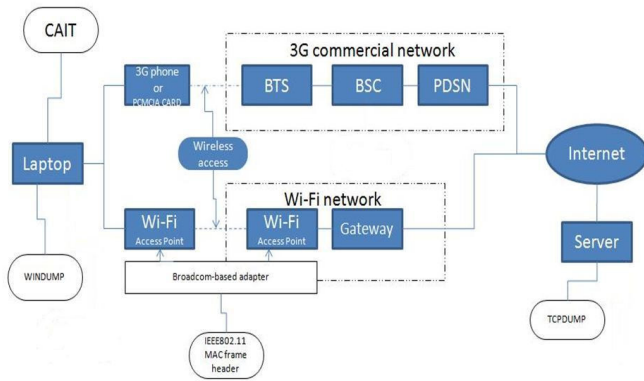
IV.   DATA COLLECTION

Fig.2 Data collection points in combined network

A series of experiments would run on the suggested network structure including pinging, downloading web pages, uploading and downing files, sending and receiving emails, and video streaming.

Measurements representing characteristics of traffic would be collected from multiple points of the combined network, as showed in Figure 2. The measurements in 3G network would

Windump at the client laptop and tcpdump at server would be used for logging detailed packet arrival information as in [5]. These logs would be used to generate a time series of key higher layer performance parameter, such as, instantaneous data sending rate, Round Trip Time (RTT) and packet loss rate, etc.

CAIT (CDMA Air Interface Tester) would be set up in the client laptop for logging physical-layer information of the 3G network in our experiments, as mentioned in [1] and [5]. Several channel related parameters would be logged, such as, Pilot SINR Ec/Io, Frame Error Rate (FER), etc. CAIT is a tool developed by Qualcomm for testing and analyzing the air interface of 3G network. [5]

Wireshark, which used to be called Ethereal, would be set up at a sniffer machine for capturing Wi-Fi frames on the air as in [6]. The 'monitor mode' of the wireless card is set for capturing IEEE 802.11 frame header, physical layer header (called the Prism2 monitor header). The Prism2 monitor header is generated by the firmware of the receiving wireless card, which includes useful physical layer information, such as, MAC Time, RSSI, signal strength, SNR and data rate.

V.   DATA SYNCHRONISATION

Synchronization is a challenge for cross-layer measurement in combined 3G and Wi-Fi networks. Our approach to synchronization of different data traces is based on timestamps. Windump and tcpdump could record the timestamps of each captured packet. In the WLAN network, timestamps of captured frames could be used for time

synchronization in the MAC layer. NTP (network time protocol), or for better accuracy, GPS, could be used for synchronising time in different machines. A GPS signal received by the 3G terminal, which could be a cell phone or PCMCIA card, could be used to timestamp .the physical layer traces measured by CAIT.

Graphic plots of characteristics at several layers based on synchronized data traces could provide a complete view of network performance.

VI.   CONCLUSIONS AND FUTURE WORK

A cross-layer measurement approach is presented in this paper. Data traces, which represent metrics at the physical layer of the 3G and Wi-Fi networks and higher layers, are collected from multiple points in the combined network at the same time.

Characteristics of lower layer and behaviours of higher layers in heterogeneous networks as well as the correlation between them will be studied.

Future research activities will investigate the performance of a combined 3G and Wi-Fi network based on the analysis of synchronized data traces collected from the framework presented in this paper.

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