Analysis of Variation in IEEE802.11k Channel Load Measurements for Neighbouring WLAN Systems

Christina THORPE[1], Sean MURPHY, Liam MURPHY
School of Computer Science and Informatics, University College Dublin, Belfield, Dublin 4.
[1]*Email: christina.thorpe@ucdconnect.ie*

Abstract: This paper focuses on analysing the variation in IEEE802.11k channel load measurements for neighbouring WLAN systems. The channel load functionality was implemented in the QualNet simulation tool, and several scenarios were configured for testing. The effects of different numbers of active systems with different traffic patterns were examined. The results obtained indicate significant variation in channel load values calculated by different stations experiencing different levels of interference. This variation leads us to question the usefulness of a single channel load measurement; hence considerable care must be taken when using and interpreting such measurements.

Keywords: Radio Resource Measurement, Channel Load Report.

1. Introduction

Wireless networks have become increasingly popular in recent years. Wireless Local Area Networks (WLAN) based on the IEEE802.11 family [1] of standards are currently the most popular radio technology used to provide wireless broadband access to IP networks. These networks are common place in the home, and are frequently used to provide public access in hotel and airports etc. In addition to this, there has also been a trend and an acceptance toward handheld devices with radio access interfaces. These devices contribute to the increasing demand for high capacity radio access networks. In such an environment, it has become increasingly necessary to provide for Radio Resource Management (RRM) to improve network efficiency and increase the ability to satisfy Quality of Service (QoS) requirements.

The IEEE802.11k Task Group [2] is currently in the final stages of developing an extension to the 802.11 family. The standardization of 802.11k will provide mechanisms for radio resource measurements. A framework of measurement requests and reports are defined to improve the provision of data from the Medium Access Control (MAC) and Physical (PHY) layers, which can be used in the higher layers to enable nodes to measure information that may help to optimize use of the radio network.

The 802.11k standard is not yet ratified; consequently, not a lot of work has been carried out in this area to date. However, some interesting research on improving confidence in the radio resource measurements is detailed in [3], this work suggests that measurement results alone may not be sufficient for quality radio resource measurement. The authors discuss an additional indicator value, which aims to provide a measure of the confidence for the quality of the resource measurement. A measuring station may not just report a single measurement result, but also the confidence interval [4] that is obtained during the measurement.

The research method employed by the authors is one of numerical analysis based on the Gilbert model [5] of the busy/idle channel time, where the correctness or suitability of the model is not discussed or quantified. The results presented in this paper were obtained through a process of simulation and the focus is placed on the variation in channel load values present over time and distance.

The channel load measurements defined in IEEE802.11k allow measuring stations to assess how occupied or idle a frequency channel is. We have implemented the channel load functionality in the QualNet 4.0 simulation tool. The objective of this research is to analyse the variation of IEEE802.11k channel load measurements for neighbouring WLAN systems. Investigations will be based on the variation of the channel load in time i.e. how does the measurement vary in time for static traffic conditions. Also, we will examine the variation between the channel load values reported by different measuring stations, located at varying distances from the AP i.e. what effect will interference from neighbouring nodes have on the calculation of the channel load.

The remainder of this paper is structured as follows: section 2 contains an overview of the 802.11k draft standard. Section 3 details the implementation of the channel load report in QualNet. Section 4 describes the simulation scenario configured for the tests. Section 5 presents the results and discussion. Finally, section 6 concludes the research presented in this paper.

2. Overview of IEEE802.11k

The IEEE 802.11k Task Group is currently working on the standardization of new mechanisms which will be used to supply measurement information to facilitate radio resource management in WLANs. IEEE802.11k is expected to be ratified later this year; therefore the measurements discussed in this work are unlikely to be changed. The standard will aim to improve the provision of lower layer information i.e. PHY and MAC data, by defining various measurement request and report frames which can be used by the upper layers. Stations in an 802.11k radio access network can gather a lot of useful information about the surrounding environment. For example, a station may collect information about other neighbouring APs, and also the link quality experienced by other neighbouring stations.

The current IEEE 802.11k draft defines a number of different types of measurements, some of which are described briefly below:

- With the beacon report, a measuring station reports the beacons or probe responses it receives during the measuring period.
- With the frame report, a measuring station reports information about all the frames it receives from other stations during a measurement period.
- In the noise histogram report, measuring stations report non-802.11 energy by sampling the medium only when the Clear Channel Assessment (CCA) indicates that no 802.11 signal is present.
- Using the hidden node report, a measuring station may report the identity and frame statistics of hidden nodes detected during the measurement period.
- In a station statistic report, a measuring station reports its statistics related to link quality and network performance during the measurement period.
- Using the medium sensing histogram report [6] [7], a measuring station reports the histogram of medium busy and idle time observed during the measurement period.

One important metric that is defined in the draft, is the channel load report. With the channel load report, a measuring station reports the fractional duration over which the carrier sensing process, i.e. CCA, indicates that the medium is busy during the measurement period. The method of measuring the channel load is standardised in 802.11k. As this report is critical to the research detailed in this paper, the channel load report is described in greater detail in section 3.

The measurements and reports described may be managed centrally, by the AP which will periodically broadcast these reports across the network. Alternatively, the standard also specifies a more distributed method where a member of the Basic Service Set (BSS) may send a frame requesting the desired information. Both approaches are used in this work.

An 802.11k compatible station must decode and interpret each Radio Measurement Request frame that it receives. It must then determine whether it is capable of performing the measurement i.e. if the requested measurement type is supported, and the impact of accepting this request may have on its own performance. The reasons for refusing a measurement request are outside the scope of the standard but may include reduced quality of service, unacceptable power consumption, or measurement scheduling conflicts, etc.

3. IEEE802.11k Channel Load Measurement Implementation in QualNet

Using the channel load report, a measuring station reports the fractional duration over which the CCA indicates that the medium is busy during a measurement period. The CCA state machine is not implemented in the simulator used for this research work, therefore modifications were necessary. The original code reported each PHY state change to the MAC; hooks were added to the code in order to model the CCA behaviour.

The four PHY states defined in QualNet are: `PHY_IDLE`, `PHY_SENSING`, `PHY_RECEIVING` and `PHY_TRANSMITTING`. Two new states were introduced to model the CCA state machine, `CCA_BUSY` and `CCA_IDLE`. The channel is considered to be `CCA_BUSY` while in any state other than `PHY_IDLE`, where it is considered to be `CCA_IDLE`. When the PHY enters a busy state the time is recorded. When the PHY enters the `PHY_IDLE` state the time is again recorded. The difference between the two timestamps is recorded as the current channel_load. The channel_load value is updated each time the PHY enters an `IDLE` state during a measurement period. In the centralised implementation, when the measurement period expires, the AP broadcasts a channel load report frame across the network.

A nodes’ PHY status change is effected by the arrival of a signal on the channel, the state can change to `PHY_RECEIVING`, `PHY_SENSING` or `PHY_IDLE`. The PHY will never be in `PHY_TRANSMITTING` when the signal arrives on the channel as it cannot be transmitting on and listening to the channel at the same time.

If the node is already in `PHY_RECEIVING` when the signal arrives, the receive and interference powers are calculated. The packet is checked for errors using a Bit Error Rate (BER) table, which is calculated using the Signal to Noise Ratio (SNR). It is then is passed to the MAC layer. If the node is in `PHY_IDLE` or `PHY_SENSING`, and the receive power is greater than or equal to the receive sensitivity, 802.11 will listen to the signal. The state is then changed to `PHY_RECEIVING` and the packet is passed to the MAC layer. If, the receive power is less than the receive sensitivity, 802.11 will not listen to the signal and it is checked to see if it changes the state of the PHY i.e. it is checked to see if it is carrier sensing.

The node is carrier sensing if the interference power plus the noise power is greater than the receive sensitivity of the lowest data rate (6Mbs for 802.11a). If the PHY is carrier sensing, the new state is set to be `PHY_SENSING`. If the PHY is not carrier sensing, the new state is set to `PHY_IDLE`. If the PHY state changes, this status change is then reported to the MAC.

4. Simulation Scenario

Figure 1 illustrates the network topology used in the simulation scenario for this research, where all APs are operating on the same channel. This topology could, for example, represent a scenario which may exist in an apartment block or building comprised of small offices. Residents may simply set up a wireless AP and proceed to use the default channel, with no consideration of network planning.

The network is made up of five separate subnets, each containing 1 AP with 10 subscribers. The distance between each AP is 260m, with each subscriber located no further than 104m from its' AP. The boundaries were calculated as follows: the transmit range of each AP for the power output levels and antenna characteristics chosen is 130m (radius r = 130), therefore, a conservative distance of 0.8r was chosen for the subscribers. The value of 2r was chosen as the distance between each AP. Table 1 details the simulation parameters used for the tests described in section 5.

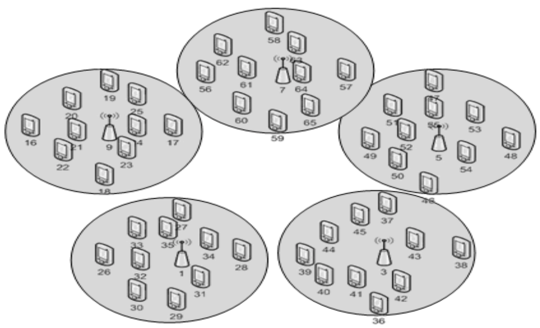


Figure 1: Network Topology for Test Scenarios

Table 1: Simulation Parameters for Test Scenarios

Simulation Parameters	
Propagation Channel Frequency	2.4 (Ghz)
Propagation Pathloss Model	Two-Ray
Propagation Shadowing Model	Constant
Propagation Shadowing Mean	4.0 (dB)
PHY Model	PHY802.11a
Antenna Model	Omnidirectional
Antenna Gain	0.0(dB)
Antenna Height	1.5(m)

5. Results and Discussion

5.1 Validation of Channel Load Measurement

This scenario is used to obtain concrete values for channel load; these values allow us to validate our implementation of the 802.11k channel load measurement. The scenario consists of one wireless node communicating through an AP. The correspondent node is connected to the internet via Ethernet. The application traffic is CBR; the wireless node sends 1450 byte packets to the fixed node for 100 seconds. The sending rate of the packets is increased at different stages throughout the simulation to model an increase in channel utilization. Table 2 details the data rate used for each CBR packet transmission. The column on the left indicates the time at which the corresponding rate is used.

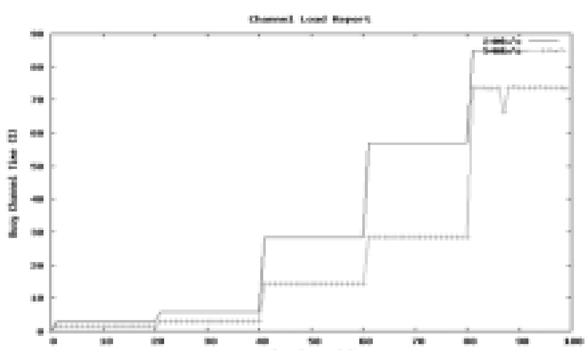


Figure 2: Channel Load Results

Table 2: Time and Corresponding Data Rate

Time (Seconds)	Data Rate Mb/s
0	0.55
20	1.1
40	5.5
60	11
80	55

The graph in Figure 2 shows the channel load values reported for IEEE802.11a at 24Mb/s and 54Mb/s link rates. When completely saturated the 24Mb/s test reports a maximum of 85% channel busy time, the 54Mb/s test reports a maximum of 74% channel busy time. The remaining simulation time is idle due to SIFs DIFs and backoff events.

5.2 Single System Test

The following scenario was simulated to examine the variation in channel load values which may be present over time and distance in an individual system or BSS; and also to obtain a reference point for a scenario with multiple systems. Two separate tests were carried out for this particular scenario; initially only downlink traffic is considered, the second test introduces uplink traffic. Firstly, each subscriber receives 1024byte CBR packets from a server connected to the internet via Ethernet at a rate of 2.6Mb/s. Secondly, the traffic is divided into 90% downlink (1024byte packets at 2.3Mb/s) and 10% uplink traffic (1024byte packets at 266Kb/s), the total traffic on the system remains constant[1].

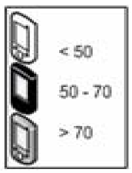


Figure 3 Topology Legend - The white icon is used for nodes which report a mean channel load value less than 50%; the black icon is used for a mean of between 50%-70%; the grey icon is for a mean of greater than 70%.

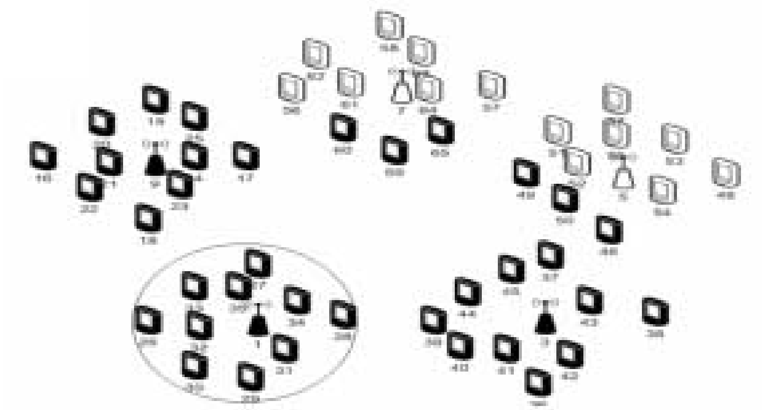


Figure 4 Topology Diagram for Single System Tests with Active System Circled

Figure 4 contains a colour coded topology diagram, which gives the spatial representation of the channel load values reported in the tests. This diagram is the same for both the downlink and mixed traffic tests, the results are not the same but rather they fall into the same categories. There is little variation in the channel load values reported from the nodes associated with AP1, each node sees the same activity on channel (60%-65%). All the nodes associated with AP3, AP9, and the nodes associated with AP5 and AP7 which are closest to the centre[2] are all affected by the interference from AP1. These nodes are within the carrier sensing range of AP1 and overhear the activity on the channel (59%-63%). The remaining nodes associated with AP5 and AP7 are further away and therefore almost out of the carrier sensing range; each of these nodes calculates a significantly lower channel load value (1% -5%).

Figure 5(a) shows the distribution of channel load values for the all downlink traffic test. The vast majority of the nodes calculate a channel load value of between 60% and 70%. 3 nodes which are further away from the active system report values between 50%-60%. The remaining nodes report values between 0% and 10%; these nodes are furthest away from the active system and therefore least affected. The aggregate throughput of AP1s' system is 22.96Mb/s, with a percentage loss of 11%. These values imply that the system is overloaded.

Figure 5(b) shows the distribution of channel load values for the mixed traffic test. There is a slight difference in the load distribution when there is uplink traffic as more nodes hear the uplink transmissions; however, this increase is not very significant. The increase in the channel load values calculated by various nodes indicates that the level of interference increases when the uplink traffic is introduced, so too does the variation. The aggregate throughput of the system decreases to 21.46Mb/s, with the percentage loss increasing also.

[1] 100% downlink and 90-10% downlink-uplink are not exactly equivalent in terms of the load they put on the 802.11 system.

[2] The white space in the middle of the five subnets is referred to as the centre in the results discussion.

The higher loss and lower throughput is due to the higher contention for the medium, which is a known characteristic of 802.11

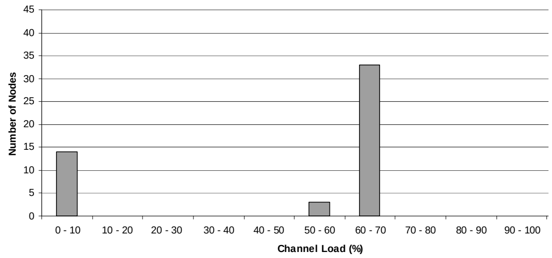


Figure 5(a) Channel Load Distribution (Down)

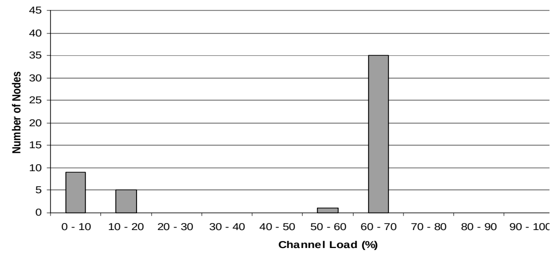


Figure 5(b) Channel Load Distribution (Up and Down)

5.3 Multiple System Test

This scenario was simulated to identify the variation in the channel load values reported when additional active systems may cause interference. Again, two separate tests were run for this scenario, one for each traffic pattern as described in the single system tests above.

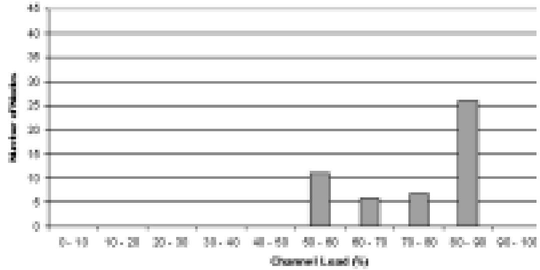
Figure 6(a) shows the topology diagram for the mean channel load values reported by each node in the system, where all the traffic is downlink. The nodes in each subnet which are closest to the centre experience the highest channel load, with values greater than 70%. These nodes all experience greater interference levels as they all are within carrier sensing range of each other. The outermost nodes in each subnet report lower load values as they experience the least interference.

Figure 6(b) illustrates the spatial distribution of channel loads reported for the mixed traffic test. The nodes in each subnet which are closest to the centre detect the lowest channel load, these values increase as we move away from the centre. These central nodes continue to experience the highest interference; however, the introduction of the uplink traffic means that the system is completely saturated. The average queue length in the network layer increases leading to a significant amount of packets being discarded from the network queue due to a lack of buffer space. The average end to end delay also increases, and the number of signals transmitted is significantly reduced, therefore lower channel load values are reported.

Figure 6(a): Multiple Systems (Down)

Figure 6(b): Multiple Systems (Up and Down)

Figure 7(a) details the distribution of channel load values for the downlink traffic test. The majority of the nodes report a value of between 80%-90%. 7 nodes which are further from the centre calculate a value between 70%-80%, The remaining 11 nodes which are furthest from the centre report a mean channel load value between 50% -60%. Figure 7(b) shows the channel load distribution for the mixed traffic test. There is a greater variation in mean channel load among nodes, where much lower channel load values are reported.



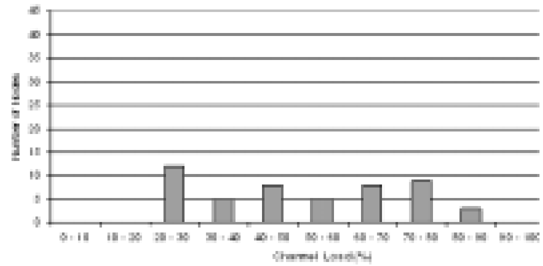


Figure 7(a): Channel Load Distribution (Down) *Figure 7(b) Channel Load Distribution (Up and Down)*

The throughput varies slightly from subnet to subnet; the maximum throughput achieved in the test with all downlink traffic is 2.53Mb/s from AP9, whereas the minimum achieved is 1.84Mb/s from AP3. When 10% uplink traffic is introduced, the aggregate throughput achieved is reduced further, with AP7 achieving less than 500Kb/s. The additional load on the system means increased congestion, higher delays, increased number of time-outs and retransmissions, and therefore lower throughput. The level of interference between each subnet is having a detrimental effect on the service being offered to their users, the system is saturated and suffers high loss.

5.4 Variation in Channel Load Measurement

Figure 8 is a plot of channel load values reported by a random node for the duration of the simulation. Variations of up to 20% can be seen (quite typical in other nodes also), this value is non negligible and would have quite a significant effect on a decision algorithm if used in RRM. Therefore, it may be insufficient to make decisions based on a single channel load value; perhaps a moving average of the channel load may provide a better metric.

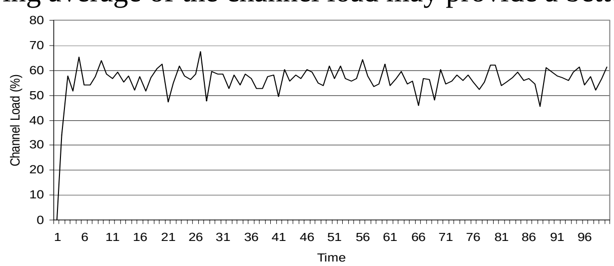


Figure 8 Variation in Channel Load over Time

5.5 Summary

The results detailed in sections 5.2 and 5.3 have shown that variation exists between the value reported by the AP and nodes (located at varying distances from the AP) in the BSS. This leads us to conclude that it is of little benefit for the AP alone to broadcast the channel load value it calculates as this value may not be correct or meaningful to every node. Likewise, it would be insufficient for a node to simply request one neighbouring node to perform a channel load measurement. A more useful channel load value may be, for example, a weighted mean of all the channel load values calculated in a BSS.

6. Conclusions

The objective of this paper was to highlight and analyse the variation in IEEE802.11k channel load measurements in neighbouring WLAN systems. The channel load measurement functionality was implemented in QualNet and validated to ensure correctness. A realistic scenario was configured and various tests were carried out using different traffic patterns.

The results obtained indicate that there is significant variation in channel loads reported by the same node at different times, there is also variation in the channel load reported from different nodes at the same time. The variation present in these measurements leads us to question the usefulness of a single channel load measurement; hence considerable care must be taken when using and interpreting such measurements. Possible future work would be to devise a method of combining the channel load values in order to represent a meaningful picture of the overall system channel load.

Acknowledgement
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