Optimization of PHY Layer Protocol for Wireless and Mobile Networks

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Abstract - Below the Media Access Control (MAC) layer is the Physical (PHY) layer which deals with the actual transmission of the bits received from the MAC layer above into electromagnetic signals. This layer is optimized to implore power management in wireless networks. Power management is a crucial issue in wireless and mobile networks. In this paper, we propose an Adaptive Context-Aware Rate Selection (ACARS) algorithm to handle the issue of power consumption in wireless networks. This algorithm is implemented by optimizing the PHY layer to transmit efficiently as the number of nodes changes and we estimate the Signal-to-Noise Ratio (SNR) to the PHY layer. Results show that by using the appropriate power management technique, ACARS is reliable and efficient for power consumption in wireless networks which is a high demand for vehicular networks.

Keywords - PHY layer; mobile networks; optimization; wireless networks; context-Information; rate adaptation; vehicular communication; IEEE802.11p; propagation phenomena; power management

I. INTRODUCTION

One of the remarkable differences between wired and wireless networks is MOBILITY. Wireless networks have emerged so well and become popular as they are deployed in almost every sector of life such as schools, hospitals, coffee shops, airports, restaurants, etc. Modern mobile devices such as laptops, Personal Digital Assistants (PDAs) are some of the tools used in deploying wireless services in these sectors. The interesting thing is that, multimedia services such as Voice over Internet Protocol (VoIP), video can be deployed using wireless technology known as Wireless Local Area Network (WLAN).

Vehicular communication networks are a type of mobile network. In this network type, the users can connect to existing networks and can then move about freely without having to worry about getting disconnected. All of these adopt same techniques of wireless networks. In this research, implementation is based on the IEEE 802.11p wireless standard.

The IEEE 802.11p standard consists of a multi-channel operation, with seven 10 MHz channels. The allocation of this spectrum has been implemented both in European Union (EU), and the United States (US) and currently being implemented in other countries as each country reviews the allocated spectrum available to their region of operation.

IEEE 802.11p is part of the family of IEEE 1609 standards which also defines higher layer protocols [15]. IEEE 802.11p operates at 5.9 GHz band US and 5.8 GHz band (Japan and Europe) with 75 MHz bandwidth that has been set aside especially for vehicular communication as part of the DSRC. This channel allocation is free, but it uses a licensed frequency band.

The PHY layer is responsible for message sending and receiving, collision detection and bit error calculation [9]. Apart from dealing with transmission of bits, the PHY layer also informs the MAC layer about signal detected on the channel, since the MAC protocol receives the packet to be transmitted. With the information, it gets from the MAC layer; it uses the information to compute a signal that represents the packet [10]. IEEE 802.11p physical layer is identical to IEEE 802.11a. IEEE 802.11a PHY layer employs 64-sub-carrier OFDM, out of which only 52 is used for actual transmission consisting of 48 data sub-carriers and four pilot sub-carriers. Moreover, the transmission power may be higher (up to 44 dBm) in 802.11p compared to that in 802.11a. IEEE 802.11p MAC layer is derived from the basic IEEE-802.11 Distributed Coordination Function (DCF).

The rest of the paper is organized as follows: Section 2 is related works, while Section 3 deals with power management in wireless networks, Section 4 optimization of the PHY layer protocol, and Section 5 is results and discussions. Finally, Section 6 concludes this paper.

II. RELATED WORKS

In [1], ray models were used to analyse performance of mobile radio channels. It this paper, Bit Error rate (BER)
performance with larger ray models was recommended for low delay spread. To suggest a solution for mobile power management in wireless networks, in [2], a dynamic power management algorithm based on Frequency-Division Multiple Access (FDMA)/ Time--Division Multiple Access (TDMA) and Code-Division Multiple Access (CDMA) was proposed. This algorithm improved network capacity and sustained battery life for mobile terminals. In [3], they proposed an optimized version of coordination technique for power saving in wireless networks that reduces energy consumption without significantly diminishing the capacity or connectivity of the network. In [4], a study on the problem of power control was made for very fast fading wireless systems, they proposed using a numerical approach to minimize the total transmit power with constraints on the user's outage probabilities, and transmit power bounds. Two distributed heuristics that adjust node transmit powers in response to topological changes and maintain minimum power for connectivity was proposed in [5]. Moreover, in [7], they presented a detailed power measurement studies on Mobile Ad-Hoc Network (MANET) with emphasis on power consumption with different antenna designs. Moreover, in [8], design focus was on investigating the effects of different transmit powers on the average power consumption and end-to-end throughput in wireless networks.

In this paper, we proposed a dynamic power management algorithm, using Rate Adaptation (RA), such that nodes can estimate SNR to the PHY layer.

III. POWER MANAGEMENT IN WIRELESS NETWORKS

Power control in wireless networks had been a major challenge. In [6], proposed a variable-range transmission power scheme on the physical and network connectivity. This approach was adopted by using a path attenuation factor. On the other hand, the network layer rather than the PHY layer was focused in [11], in order to design a power sensitive network in wireless networks.

In this paper, we have implemented a dynamic power control algorithm, by considering the PHY layer protocol, by adopting the Receive Signal Strength Indicator (RSSI), which is a true indicator of the channel quality of any network.

A. Propagation phenomena

Propagation phenomena are common factors that infer in the performance of wireless and mobile communications. They range from tall buildings, trees, fading processes and other environmental factors. In this paper, we have considered free space path loss and shadowing to analyze the performance of RAs in different environments and transmit powers.

B. Free Space Path Loss

Free space path loss model is a power off that relates to distance. Due to high mobility of vehicles as speed changes, the distance between the transmitter and receiver changes. This makes empirical free space path loss necessary in order to model the effect of distance on packet delivery probability. This space loss accounts for the loss due to spreading of radio frequency (RF) energy as transmission of signals propagates through free space. From the equation of path loss, it is seen that the power density is reduced by \( \frac{1}{r^2} \) as distance is increased.

\[
P_{rx} = P_{tx} \left( \frac{\lambda}{4\pi R} \right)^2
\]

Where \( P_{rx} \) is the power density. In free space, the power of electromagnetic radiation varies inversely with the square of the distance, making distance an ideal indicator of signal level, as well as loss rate. Due to imperfect propagation environment, in practice it is not exactly the inverse square. Distance between sender and receiver gives a high correlation between signal level and error rate as this affects the number of transmitted packets that will be received [19].

\[
g(t) = g_p(t) + g_s(t) + g_m(t)
\]

\[
P_{rx} = P_{tx} - g_t
\]

\[
RSS = P_{rx} - P_{noise}
\]

Where \( g_t \) is power gain, \( g_p(t) \) is path loss, \( g_s(t) + g_m(t) \) is shadowing and \( g_m(t) \) is multipath fading and RSS is the received signal strength.

C. Shadowing

Fading is a terminology employed in describing fluctuations of the received signal as a result of multipath propagation. Fading can slow and fast and also can be defined in terms of flat or frequency selectivity.

Path loss is a function of antenna heights and the environment and distance. Hence, the predicted path loss for a system operated in a particular environment will, therefore, be constant for a given base-to-mobile distance [14].

Fast fading is sometimes called log-normal fading because a log-normal distribution tends to be the best to describe the fading process. Fading occurs as a result of scattering from distant large objects (shadowing) unlike in the case of fast fading and hence it also termed as large-scale fading [13].

Power control is an efficient technique to combat the effect of multipath fading that affects the received signals in wireless networks.

Communication channel is a time-varying power gain which consists of path loss, log-normal shadowing and multipath fading. The receivers experience a desired signal gain with respect to the transmit power \( P_t \) used by
the transmitter. Algorithm 1 shows how Received Signal Strength (RSS) is calculated. Figure 1 is the two ray diagram that helps to implement Algorithm 1. Algorithm 1 calculates path loss and RSS depending on the values of d. d is the cross distance, P_r is received power P_t is transmit power, and P_l is path loss.

Algorithm 1 Received Signal Strength Algorithm

1: Take transmitted signal strength P_t
2: Calculate the distance between sender and receiver d
3: Calculate the cross distance d_c
4: IF d>d_c then
5: Calculate Friis path loss P_l
6: ELSE
7: Calculate received signal strength P_r = P_t - P_l
8: ENDIF.

IV. OPTIMIZATION OF THE PHY LAYER PROTOCOL

In this section, we will consider the integration power control scheme in ACARS. With this integration of power control into ACARS and existing rate adaptation algorithm, we will evaluate the optimization process of power management in various rate selection schemes.

A. Overview of ACARS

We developed ACARS to improve its performance over MODIFIEDCARS; a modified version of the original CARS algorithm since all of its implementation were not disclosed. ACARS is designed and implemented to estimate SNR to the PHY layer. It can handle hidden node problem by using Request-To-Send/Clear-To-Send (RTS/CTS) frame exchange.

Algorithm 2 is a summary of ACARS implementation. The two key functions in this algorithm are E_C and E_H. E_C uses context-information (ctx) as input parameter and helps to implement line 17 of Algorithm 2 which is Packet Error Rate (PER) P. E_H uses past transmission statistics for each bit-rate. N is the maximum number of retransmission, p is penalty of unsuccessful transmission, a indicates when to give priority to either ctx or E_H. From the look up table for Bit Error Rate (BER) table, this algorithm uses \( \tau \) from the BER table for Bit Error Rate (BER) generated for each node. The goal of Algorithm 1 is to return the best rate to be chosen for transmission.

Algorithm 2 The Adaptive Context-Aware Rate Selection Algorithm

Function: ACARS_GetRate

Output: \( \partial \)
Input: ctx, \( \alpha \), \( P_L \)

1: Update counter of packet transmissions
2: Update average RSSs of recent ACKs (RSS)
3: Determine \( \alpha \) by using \( \alpha = \max(0, \min(1, v/S)) \)
4: Compute back-off using
5: back-off = \( CW_{size} \cdot t_{slot} \)
6: Decrement all back-off counters
7: Update the simulation time accordingly
8: Requires: \( V_{mob} \)
9: (t, v, \( V_{veh} \), \( A_{pos} \), \( C_R \), n, \( X_{max} \), ctx)
10: Compute \( \tau \) from the BER table
11: Compute E_C using
12: E_C = \( \varphi \cdot E_C \cdot TV \)
13: Determine E_H using
14: E_H = \( \varphi \cdot E_H \cdot TV \)
15: Compute E_H using
16: E_H = \( \varphi \cdot E_H \cdot TV \cdot \partial \cdot TV \) = \( \varphi \cdot E_H \cdot TV \cdot \partial \cdot TV \) \cdot (1-a) + \tau \cdot a
17: Compute P using
18: P = \( E_C \cdot \alpha + (1-\varphi \cdot \alpha) \cdot E_H \)
19: Select \( \partial \)
20: IF \( \partial > \max \) then
21: Update link condition
22: Best-rate \( \leftarrow \) bit-rate
23: \( \max \leftarrow \) Thr
24: ENDIF.
B. Simulation Model

IEEE 802.11p is an extension of 802.11 wireless local area network (LAN) medium access (MAC) and PHY layer in order to add WAVE. Three different PHY layer mode has been defined by 802.11-2007 standard. They are the 20 MHz, 10 MHz and 5 MHz.

The IEEE 802.11p standard consists of a multi-channel operation, with seven 10 MHz channels (there are no guard channels specified currently, so the frequency band is contiguous) at the 5850-5920 MHz range (usually abbreviated to the 5.9 GHz range) of the spectrum. The allocation of this spectrum has been implemented both in the European Union (EU) and the United States (US) and currently being implemented in other countries as each country reviews the allocated spectrum available to their region of operation. Our simulation is implemented with the 5.9 GHz range.

In this simulation model, all vehicles act as clients. We use a fixed base station as server which is similar to what is obtained in cities and highways having road-side units (e.g., kiosks and cafes) with wireless services. Our scenario consists of a road of length 1000 m with multiple lanes. The base station is located at the middle of the road. Vehicles select their speeds uniformly over the range Speed\text{avg} \times 0.75; \ Speed\text{avg} \times 1.25\text{km/h}. Tables I shows the simulation parameters, path loss exponents and shadowing deviations respectively. Figure 2 shows the V2I configuration used in our simulation.

\[
\text{Speed}_{\text{avg}} \times 0.75, \ \text{Speed}_{\text{avg}} \times 1.25\text{km/h} \quad (5)
\]

<table>
<thead>
<tr>
<th>Parameters (Units)</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of Road (m)</td>
<td>1000</td>
</tr>
<tr>
<td>Number of Vehicles</td>
<td>150</td>
</tr>
<tr>
<td>Position of AP (m)</td>
<td>500</td>
</tr>
<tr>
<td>PHY and MAC Protocol</td>
<td>802.11p</td>
</tr>
<tr>
<td>Frequency (GHz)</td>
<td>5.89</td>
</tr>
<tr>
<td>Normalized Transmit Power (mW)</td>
<td>40, 50</td>
</tr>
<tr>
<td>Noise Power (dBm)</td>
<td>-90</td>
</tr>
<tr>
<td>(\gamma) (Path Loss exponent), (Shadowed Urban cellular radio, obstructed in building)</td>
<td>2.7-4</td>
</tr>
<tr>
<td>(\sigma) (dB) (Sigma), outdoors</td>
<td>3-12</td>
</tr>
<tr>
<td>Communication Range (m)</td>
<td>300</td>
</tr>
<tr>
<td>DIFS ((\mu))s</td>
<td>50</td>
</tr>
<tr>
<td>SIFS ((\mu))s</td>
<td>30</td>
</tr>
<tr>
<td>PHY (bits)</td>
<td>192</td>
</tr>
<tr>
<td>HMAC (bits)</td>
<td>200</td>
</tr>
<tr>
<td>Data rate (Mbps)</td>
<td>3, 4.5, 6, 9, 12, 24, 27</td>
</tr>
<tr>
<td>Maximum Retransmission</td>
<td>3</td>
</tr>
</tbody>
</table>

Speed\text{avg} of 55 km/h was used for the different number of vehicles. The distance between vehicles and access point (AP) or road side unit (RSU) was determined from equation (5). Parameters used in this simulation are listed in Table I.

![Network Setup](image)

**Figure 2. Network Setup.**

V. RESULTS AND DISCUSSIONS

In this section, we will analyze the results obtained for simulated rate adaptation algorithms using MATLAB. We will also discuss the results obtained from these rate adaptation schemes and evaluate on their performance in order to show the impact of optimizing power control scheme in rate adaptation algorithms.

A. Results

In this network configuration, each time when a vehicle enters into the communication range, it will communicate with the road side unit. It will add new vehicle information like vehicle speed, position, distance, etc. This information will help the road side unit to broadcast the emergency information to the vehicle. Every minute so many vehicles will leave and enter the communication range with high speed. Roadside unit will communicate to vehicles as soon as they enter the communication range, because for example if there are no vehicles within range and there is an accident or emergency message, at that time; as soon as any vehicle enter the range, message will propagate through the first entered vehicle in that communication range. Communication is only helping communication when there is no vehicle in the cluster range.

B. Discussions

Considering the energy consumption of communicating vehicles in vehicular communications. Power is one of the challenging issues to combat with. Since this is a major concern, ACARS is designed to alleviate this problem in vehicular communications. The results obtained from simulations show the trend of improvement of ACARS over MODIFIEDCARS, which we developed ACARS from.

From Figure 3, ACARS having a good power control management as a result of AP coordination, has low energy consumption compared to MODIFIEDCARS.
As can be observed in Figure 4, that ACARS can adapt to the fast variation of channel conditions and also estimate SNR from the PHY layer to improve its performs as an SNR-based rate adaptation scheme. From this figure, SAMPLERATE performed poorly and cannot adapt to the channel condition with this transmit power. The values from this simulation are regarded as a real world scenario [12]. With low transmit power, it reduces the interference seen by the potential transmitter, but requires more forwarding nodes to reach their intended destination.

Increasing transmit power increases connectivity and reduces network capacity [6]. It reduces forwarding nodes to reach each destination. From Figure 4, we increased the transmit power to analyse the behaviour of nodes in a shadowed urban cellular radio and obstructed in building environments. Result show that ACARS performed better than MODIFIEDCARS. SAMPLERATE did not also perform very well in this regards because it cannot adapt to channel changes to adapt it transmission time for each bit rate. ONOE performed better in this regard, because it was able to choose each credit to change bit rate as the channel condition changes.

From Figure 5, AARF performed better than all other schemes, because it can probe the transmission packets faster to adapt to the various propagation phenomena. ACARS, also performed well compared to MODIFIEDCARS, ONOE and SAMPLERATE, because it can estimate SNR to the PHY layer.

VI. CONCLUSION AND FUTURE WORKS

From results obtained, we have seen the impact of optimizing power control in rate adaptation algorithms. Results show that optimization process especially in ACARS yields better performance which will have much usefulness in the application of DSRC technology (with a focus on vehicular communication).
One of our key contributions in this paper is the optimization of the PHY layer to yield a reliable and efficient power control scheme that can estimate SNR to the PHY layer. The results obtained can be applicable in safety messaging in Dedicated Short Range Communications (DSRC), reduce network congestion, improve the Quality of Service (QoS) and collision avoidance in vehicular networks.

A. Future works

In the future, we will consider more path loss exponents and also investigate it with a Vehicle-to-Vehicle communication (V2V) network. We will also want to simulate using other platforms, such as OMNeT++, Network Simulator (NS) etc.

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REFERENCES


