Effect of Radio Platform Noise on Existing MAC Protocols in use in Ad Hoc Wireless Networks and its Solution

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Abstract: *Ad Hoc wireless networks represent a communication paradigm that is relatively new. It has the potential to provide ubiquitous communication and this is the reason why it is generating such keen interest in the world of communication. One of the key factors for the success of Ad Hoc wireless networks is smooth interaction between the medium access control (MAC) layer and the physical layer. In this paper, we have modified the correlation between ALOHA, an established MAC protocol and the noise model of the physical layer for a circuit switched network. This modified model will help to estimate the maximum effective transport capacity more correctly in-between the nodes of Ad Hoc wireless networks. This model will give more precise result since it has also taken into account the noise generated by the node-radio platform.*

Key-words: *ALOHA, Inter-node interference (INI), Medium access control (MAC), Signal-to-noise ratio (SNR), Transport capacity*

1. Introduction

Ad Hoc wireless networks promise newer and ubiquitous communication anywhere since they are independent of any infrastructure and so-called base-stations. At the same time, such networks face quite a few challenges with respect to the wireless networks with defined bases and infrastructures.

One of the biggest challenges is to operate with low capacity battery and omni-directional antenna. As a result, the signal –to-noise ratio (SNR) at any receiver node cannot be increased by classical means like increasing the transmitter power or making the signal directive. Therefore, the noise element at the receiver assumes far greater significance.

We know that the noise element at any wireless receiver is taken to be the addition of two factors- one is the link noise and the other is the thermal noise both of which are functions of the bandwidth of the receiver. If we consider the overall construction of any node-radio, it consists of three modules namely, (i) receiver and transmitter block; (ii) power supply block and (iii) the control function block.

The control block for any present day radio plays the most important role- it provides functions like channel selection, phase locked loop(PLL) control, switching of active mode and sleep mode of the microcontroller etc. and ,therefore, this block has become the integral part of even radios used in the nodes of the Ad Hoc wireless networks.

Hence, it is but logical that this block has to be considered for any possible additional noise factor while the SNR of the received signal is considered.

Now, let us examine the data transfer mechanism in an Ad Hoc wireless network so that the possible degradation due to fundamental performance limits can be explained.

The concept of transport capacity has been introduced to quantify the achievable transmission of information in the Ad Hoc wireless networks and it involves two parameters- the rate of data transfer and the distance between the source node and the destination node.

In [1], the authors have computed the transport capacity of stationary wireless networks. It also assumes that inter-node interference (INI) will be nil for the given Ad Hoc wireless network. This is possible only when the SNR for both the source and destination nodes is above the threshold value for the network. Here, SNR considers both interference and thermal noise.

This approach [1], does not give a clear picture about the influence of physical layer characteristics and of the medium access control (MAC) protocol on the achievable performance.

The paper [2] shows how physical layer and MAC layer are interrelated. We have applied the results to establish that our suggested modification will make the predicted transport capacity more correct and realistic in Ad Hoc wireless networks.

The remainder of this paper is structured as follows. In section 2, a model for circuit switched Ad Hoc wireless networks is described. Section 3 details the background logic and modification of the model. In section 4, ALOHA MAC protocol and its operation with respect to new model is explained. Section 5 draws the conclusion.

2. Ad Hoc wireless networks and circuit switching

If we consider any Ad Hoc wireless network with reasonably high node spatial density, it is but natural that inter-node interference will occur most of the time.

Now, concept of effective transport capacity [1] is a very useful concept to compare different mechanisms in an Ad Hoc wireless network and it represents the rate-distance product actually carried by the network. The rate-distance is basically the product of the maximum data rate and maximum distance so that the product can be used as an indicator for reliable data transfer in the wireless network.

If the physical model is one of non-interference, then it is assumed that the SNR at the receiving node is above the threshold value for the Ad Hoc wireless network in spite of interference from other active nodes of the same network or other adjoining networks. In [1], it is also assumed that the network is a stationary one. Therefore, we have also assumed these conditions for our paper.

Different schemes like spread-spectrum technique can be employed to combat problem of interference but in this paper this angle has not been pursued and the attention is on the random access MAC scheme namely, ALOHA. Techniques like automatic repeat request(ARQ) have not been considered since such techniques are based on the concept of re-transmission of the data packets and for Ad Hoc wireless networks, energy conservation at the nodes is one of critical importance. Rather, we have considered a bit-level interference analysis using ALOHA MAC protocol.

The objective of any Ad Hoc wireless network is to reach data to the desired destination node from the originating source node – the route usually consists of a number of nodes giving rise to multi-hop communication. For a created route, the nodes involved can be thought of as forming a communication tube.

These tubes can bend if the nodes become mobile and the configuration of the tubes changes when the existing route does not work any longer necessitating drop or insert of nodes. The creation of a private path between the source and destination nodes resembles circuit switching [3].

In each of such tubes, there are gaps between consecutive packets to ensure that there is no INI. It is assumed in the rest of this paper that the packet transmission is Poisson distributed with parameter λ. It implies that the average inter-arrival rate between two consecutive packets is $1/\lambda$.

If R_b is the channel data-rate of any node in the Ad Hoc wireless network and L is the number of bits in a packet, the packet duration is given by (L/R_b). If (L/R_b) is sufficiently smaller than $1/\lambda$, the inter-arrival time, the packets transmitted in the two tubes may not overlap reducing significantly the inter-route interference. This idea of non interference applies to the ALOHA scheme.

3. The mathematical model

On the basis of the communication theoretic framework developed in [2], we have considered a node distribution pattern in which the total of N nodes of the Ad Hoc wireless network are placed at the vertices of a square grid inside a circular area A.

The node spatial density, ρs, defined as the number of nodes per unit area is then (N/A). If r_L is the minimum inter-node distance, then:

$$r_L \approx 1/(\rho s)^{½} \quad \text{------(1)}$$

It is assumed subsequently that a multi-hop route is formed by a sequence of minimum length hops.

This is a very powerful strategy to minimize the end-to-end bit error rate (BER) keeping the transmission power level to a minimum [2] [4]. If BER at the end of a single hop is denoted by p_L and it is assumed that (i) each node of the network is a regenerative one and that (ii) the uncorrected errors accumulate, it is possible to show [2], that the BER at the end of the nth. link of a multi-hop route can be expressed as:

$$P_b^{(n)} \approx 1-(1-p_L)^n \quad \text{-------(2)}$$

The average BER can be calculated by evaluating (1) for an average number of hops. If it is assumed that the number of hops is uniformly distributed between 1 and $n_h^{max} = 2(N/\pi)^{½}$, the average number of hops becomes

$$n_h^{av} = [((N/\pi)^{½}].$$

Hence, from (1) and (2):

$$P_b^{av} = P_b(n_h^{av}) \approx 1-(1-p_L)^{[((N/\pi)^{½}]} \quad \text{---(3)}$$

Where, P_b^{av} is the average value of BER.

The link BER, p_L is directly related to the SNR at the destination node of the link and let it be denoted by SNR_L. We are further assuming that that the transmitted signal is affected only by the free-space loss. Therefore, the received signal power at the end of a minimum length hop will be governed by Friis equation.

This received power $P_r^{(r_L)}$ can be expressed as:

$$P_r^{(r_L)} = (\alpha . P_t / r_L^2) \approx \alpha . \rho s \; . P_t \; [\text{using (1)}]$$

$$= \frac{G_t . G_r . \lambda_c^2}{(4\pi)^2 \; . L} . \rho s . P_t \quad \text{---(4)}$$

where, P_t is the power transmitted from each node of the link in the Ad Hoc wireless network, λ_c is the wavelength of the carrier frequency, G_t and G_r are the gains of the transmitter and receiver antenna respectively and L is the loss factor of the medium.

Generally, two distinct cases are distinguished based on the presence or absence of INI – one is the ideal case in which the interference is totally absent and second one in which the INI is considered to be present. We have analysed the realistic or the second case in more detail and added an additional element in the model.

i) Ideal case – in this case, interference from other nodes is assumed to be absent so that the noise at the receiving node consists only of the thermal noise generated at the receiver. The link SNR can be expressed as

$$SNR_L^{noINI} = \frac{P_r^{(rL)}}{P_{thermal}} \quad \text{-----(5)}$$

where $P_{thermal}$ is the thermal noise power at the receiver.

ii) Realistic case(INI present) – in such a scenario, the interfering signals from other nodes of the Ad Hoc wireless network may be treated as additive white noise independent from the thermal noise of the receiving node. The SNR at the end of a minimum link length can be expressed as

$$SNR_L^{INI} = \frac{P_r^{(rL)}}{P_{thermal} + P_{INT}} \quad \text{------(6)}$$

where P_{INT} is the interfering signal power.

3A. The modification to the SNR

For any new generation radio, the operation of the radio is controlled mostly by intelligent programs which run on fast micro-controllers. This control platform introduces significant noise in the radio particularly the receiver mixer section[..]. It may cause desensitization of radios at particular frequency thereby reducing the range or increasing the noise in the receiver. The resultant SNR should ,therefore, be expressed as:

$$SNR_L^{net} = \frac{P_r^{(rL)}}{P_{thermal} + P_{INT} + Ppf} \quad \text{------(7)}$$

where, P_{pf} represents the platform noise power at the receiving node of the Ad Hoc wireless network.

We refer to full connectivity when at the end of the desired multi-hop communication route, the BER is lower than a maximum tolerable value. Since the link BER is a decreasing function of the SNR obtained in the link, it is but logical that SNR_L has to exceed a certain minimum value of SNR_L^{min} . It again depends on P_b^{max} and N.

Since, the platform noise power may change the SNR value of the link drastically, it is very important that this factor is removed through proper hardware design or taken care of in calculating the range.

4. ALOHA MAC Protocol

The basic principle of Aloha protocol is the provision that each node, without sensing the channel occupancy, transmits whenever it has information to transmit. An Ad Hoc wireless network with multi-hops can use this protocol easily.

It is seen that in the case of ALOHA protocol, the link SNR is a monotonically increasing function of the transmitted power and node spatial density and is lower than a maximum value SNR_L for ALOHA. If there is strong internal interference as already discussed in section 3, the SNR of the link degrades and increasing the transmitter power does not solve the problem of poor SNR for the link.

Moreover, since the restriction on transmitter power level for the nodes of Ad Hoc wireless networks is severe because of importance of energy conservation, it is not a solution at all.

In [2],[5] , a new method for bit-level analysis is proposed and the BER performance with ALOHA protocol is analyzed. We have taken part of the results to evaluate the effective transport capacity and to show how it is affected by the presence of strong interference from the controller and digital hardware of the radio control circuit.

It is possible to show that the interference power appearing in the SNR expression (6) can be expressed as :

$$P_{INT}^{aloha} \approx \alpha.\, \rho s\ .\, P_t\ (1 - e^{-\lambda D_p})\ .\ K \text{ -----(8)}$$

Where D_p is the packet duration, given by L / R_b and K is a factor dependent on the maximum tier number in a square grid network. The $SNR_L^{aloha,max}$ can be written as :

$$SNR_L^{aloha,max} = \lim_{P_t,\ \rho s \to \infty} SNR_L^{aloha} \text{ --(9)}$$

For strong interfering power represented by P_{pf} in equation (7), this SNR equation for Ad Hoc wireless networks using ALOHA mac protocol will have a serious implication.

The $SNR_L^{aloha,max}$ will decrease and in some cases, it may become lower than the value SNR_L^{min} required for full connectivity of the Ad Hoc wireless network.

It will fail irrespective of the transmitted power level and node spatial density.

5. Solution

Such unpredictability of SNR value can be a serious problem for successful operation of Ad Hoc wireless networks. To prevent such situation, hardware solutions were suggested after exhaustive experiments in our paper [8].

The paper describes two possible solutions to eliminate the problem of radio frequency interference(RFI) from the radio platform.

The second of the solution is a better one and briefly, it has a built-in intelligent circuit which checks continuously the SNR of the radio of the receivers with the help of the radio signal strength indicator(RSSI) output from the intermediate frequency(IF) processor integrated circuit(IC).

The micro-controller oscillator frequency is changed under program control till a satisfactory RSSI is achieved or in other words, a good and reliable SNR value is attained in the receiver.

When this is achieved, we can say that the interference factor as shown in equation (7) can be neglected for all practical purposes.

6. Conclusion

We have shown that the noise factors present in an wireless link are contributed by more than one element and one of those is the RFI from the platform of the radios of the Ad Hoc wireless network nodes. This can be the most damaging one since the desensitization of the receiver can be carrier frequency dependent and again ,in turn, the spurious frequency component could be any sub-harmonic of the controller clock frequency.

Hence, unless the root cause of this possible interference is eliminated in the hardware design stage, the performance of the Ad Hoc wireless networks can continue to be unreliable connectivity-wise and BER-wise.

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Prabir Banerjee obtained his Bachelor's degree in B.E.Tel.E from the ETC department of Jadavpur University in 1980 and his M.E.Tel.E. degree in Computer Engineering from Jadavpur University in 1982.

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