A MAC Protocol for Wireless Ad Hoc Networks with Power Control

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***Abstract*- We propose a MAC protocol which achieves better spatial reuse of spectrum thanks to power adjustments based on the number of neighbors in the one-hop neighborhood. Through many simulations we show that our algorithm outperforms the IEEE 802.11 standard, also in high interference environments.**

***Keywords:* ad hoc networks, MAC protocols, power control**

I. INTRODUCTION

IEEE 802.11 [1] has become the standard for Wireless LAN's both in infrastructure and in ad hoc mode, although originally it was developed for a single access point scenario. Probably this is the main reason for many problems and limitations arising in a pure wireless multi-hop network, where the nodes are not within the transmission range of one another and everyone has to contend for the access to the radio channel. The standard specifies the medium access control mechanism, DCF (Distributed Coordination Function) which has been developed to use within both infrastructureless and infrastructure network configurations. The DCF is based on CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance). In this paper we have designed a new MAC protocol which adjust the transmission power based on the number of neighbors in the 1-hop neighborhood in order to gain in throughput, packet loss and delay.

The remainder of the paper is organized as follows. In Section II the related work is presented. In Section III the basic algorithm and definitions of our proposed protocol are described. Details of the simulations and results are presented in Section IV. Finally, concluding remarks are formulated in the last section.

II. RELATED WORK

The CSMA/CA mechanism presupposes that each node uses a certain fixed (or maximum) transmission power for the transmission of each packet. The 802.11 standard also assumes that the network is homogeneous. However, wireless terminals are usually equipped with batteries that provide limited amount of energy and limited transmission power. Since the power level determines the network topology, the energy consumption is an important factor in ad hoc networks. One way to conserve energy supported by the standard [1] is the power saving mechanism. A second approach is to use a *power control* scheme, that allows to vary the transmit power in order to reduce energy consumption. Many studies have shown that in a real-life network, power control protocols can achieve a better power conservation and a higher system throughput through better spatial reuse of the spectrum [6], [8], [2], [3], [4].

A simple basic power control scheme is based on the assumption that RTS/CTS packets can be transmitted with the highest power level and DATA/ACK packets with a minimum power level [6], [8]. It should be taken into consideration that different power levels among different nodes cause asymmetric links. In the basic scheme, a transmission power level for DATA/ACK packets is determined using two different methods: by calculating the desired power level by the receiver or by the transmitter (bases on received power level p_r, transmitted power level p_{max}, and an equation

$$p_{desired} = p_{max}/p_r * Rx_{tresh} * c, \qquad (1)$$

where Rx_{tresh} is minimal necessary received signal strength and a constant c). In order to solve the problem with nodes in the CSR (Carrier Sense Range) a solution is proposed in [4], where the sender periodically transmits DATA at the maximal power level, p_{max}, just for enough time so that nodes in the CSR can sense it. Nodes in the CSR defer their transmission only for the EIFS (Extended InterFrame Space [1]) duration, so the transmit power for DATA is increased once every EIFS duration and also the interval using p_{max} should be larger than the time required for physical carrier sensing.

Another interesting solution has been proposed in [3]. The protocol achieves energy conservation by dynamically adjusting the transmission range on the fly at each node and thus increasing spatial reuse of the spectrum. The algorithm derives the minimum power from the power strengths P_{ij} (equation 2) (taking into account: minimum SIR threshold (SIR_{thresh}), the background noise power (N_0), receiver power (P_{re}) at node j, transmission power (P_{tr}) of node i) of the received packets, and record it in a local table. Each node uses local information (guarantees scalability and zero communication overhead) to determine the minimum required transmission power;

$$P_{ij} = P_{ji} = \frac{SIR_{thresh} * N_0}{P_{re}} * P_{tr}. \tag{2}$$

In [2] an adaptive solution is proposed, where RTS/CTS packets are transmitted with the minimal power level on the first t attempts (t is a dynamically tunable parameter). If all t attempts fail then the power level of RTS/CTS is incremented by $\omega(P_{max} - P_{ij})$ for every additional failure (ω is a tunable coefficient). In the worst case, the sender will use the maximal transmission power level. In [5] load-sensitive algorithms are proposed that adapt the transmission range based on traffic load conditions (every node estimates the contention time as the sum of the transmission time + backoff time due to a collision [1]).

III. PROPOSED POWER CONTROL SOLUTION

The basic idea of our protocol is to adjust power if the number of neighbors increases in order to achieve a better spatial reuse, a better throughput and a smaller packet loss. Each node can estimate how many neighbors it has in its 1-hop neighborhood, based on successfully detected signals or using the table that is built by the routing mechanism. If the number of neighbors is different from our desired number of neighbors, $number\_of\_Neigh_{MAX}$, then we adjust the power. The basic principle is similar to the one introduced in [9], but has a different purpose, namely power control instead of topology control. In [9], the neighbors in the transmission range are discovered (with initial power p_0). If the number of neighbors is greater than the desired number ($k = 6$ is used), then the closest neighbors are retained as the neighboring nodes and the rest is purged from the neighboring list. The change of the desired transmit power p_d is applied by using a logarithmic increase and decrease of power [10] depending on the number of neighbors:

$$p_d = p_c - 5 * \varepsilon * log(\frac{d_d}{d_c})\ [dB] \tag{3}$$

where p_c is the current used power, d_d the desired number of neighbors, d_c, the current number of neighbors and the value ε is usually between 2 and 5.

In our algorithm, presented below, we do not purge any neighbor from the list, but only adjust the power. If the number of neighbors increases we decrease our power and if the number of neighbors decreases we increase our power. Thus, the algorithm is executed every time when the number of neighbors changes. In each increase or decrease (Pt_{DIFF}) in the desired transmission power Pt_{TR} (equation 7) we take into account the transmission power history Pt_{HIST} (equation 6). The transmission power history is the old calculated value Pt_{TR}. We have assumed that $nr\_of\_Neigh_{MAX}$ is fixed and equal to 5. Different values of $nr\_of\_Neigh_{MAX}$ (e.g. $3, 4, 5, 6$) will be discussed in future work. The pseudocode of the algorithm is presented below:

```
IF $(nr\_of\_Neigh_{CURR} <= nr\_of\_Neigh_{MAX})$
        $Pt_{TR} = Pt_{MAX};$                                         (4)
IF $(nr\_of\_Neigh_{CURR} > nr\_of\_Neigh_{MAX})$
        $x = \frac{nr\_of\_Neigh_{CURR}}{nr\_of\_Neigh_{MAX}};$       (5)
        $Pt_{DIFF} = \varepsilon * log_{10}(x) * Pt_{HIST};$          (6)
IF $(nr\_of\_Neigh_N < nr\_of\_Neigh_{N-1})$
OR IF $(nr\_of\_Neigh_N > nr\_of\_Neigh_{N-1})$
        $Pt_{TR} = Pt_{MAX} - Pt_{DIFF};$                             (7)
ELSE IF $(nr\_of\_Neigh_N == nr\_of\_Neigh_{N-1})$
Do nothing,
```

where $nr\_of\_Neigh_{CURR}$ is the current number of neighbors, $nr\_of\_Neigh_{MAX}$ is the desired number of neighbors, ε is equal to $\frac{1}{nr\_of\_Neigh_{MAX}}$ and Pt_{MAX} is the maximal transmission power. An alternative approach is to change the power when the number of neighbors decreases:

```
IF $(nr\_of\_Neigh_N < nr\_of\_Neigh_{N-1})$
    Take the corresponding power from the $List_{NP}$,        (8)
```

where the list $List_{NP}$ maintains consecutive numbers of neighbors and corresponding transmission powers.

However we have noticed in our simulations that the first approach (equation 7) is better than the second (equation 8), because every time when the number of neighbors increases and then descreases the algorithm corrects the value of the transmission power (e.g. for $nr\_of\_Neigh_{CURR} = 7$, the desired trasmittion power is $Pt_{TR} = 6792693e^{-3}$ $[W]$, then for $nr\_of\_Neigh_{CURR} = 8$ (first increase), $Pt_{TR} = 6731419e^{-3}$ $[W]$, $nr\_of\_Neigh_{CURR} = 7$ (first decrease), $Pt_{TR} = 6801166e^{-3}$ $[W]$, $nr\_of\_Neigh_{CURR} = 8$ (second increase), $Pt_{TR} = 6731153e^{-3}$ $[W]$). This correction of the value of the transmission power always takes into account the power history from all 'rounds'. The first approach is better not only because it achieves a better performance but also because the nodes do not need to store the list $List_{NP}$ with the numbers of neighbors and corresponding powers. Figure 1 shows the change of the power for the first (*PowerSc*_5) and second approach (*PowerSc*_*C*_5). In order to see this small correction of values a zoom of the plot is shown.

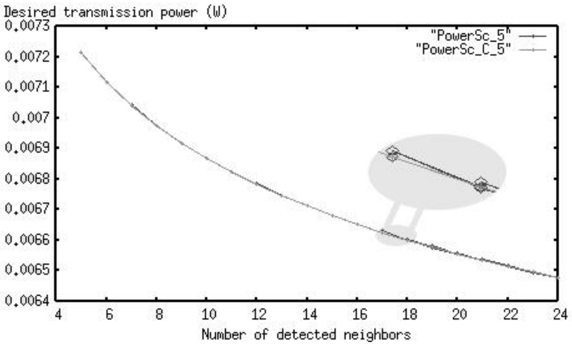

Fig. 1. The change of the transmission power

The increase and decrease (Pt_{DIFF}) in the desired transmission power Pt_{TR} is limited by the maximum and minimum power specified by the transceiver used by the nodes.

IV. SIMULATION AND RESULTS

The proposed power control mechanism has been implemented in the ns-2.27 network simulator [11]. The simulations have been carried out for various topologies and scenarios. We have analized the performance of the network with different traffic. Figures below show the evolution of throughput, delay and packet loss. The following performance metrics are used:

- Total packets received
- Average Throughput - $\frac{Total_{Nr\_recv}}{Trans_{bitrate} * Time_{Sim}}$ $[Mbps]$
- Average Delay
- Packets Loss - $\frac{Total_{Nr\_drop}}{Total_{Nr\_sent}}$.

In Table I we present the simulation parameters. We have applied the *Shadowing Propagation Model* [11] with different parameters in order to analyze performance of our protocols and the standard IEEE 802.11 DCF in different interference environments, so with different fading effects e.g *Outdoor - Shadowed urban area, Office hard or soft partition, Factory, line-of-sight or obstructed*.

Parameter	**Values**
Number of nodes	8, 25
Simulations area (m)	500 x 500
Topology	Ring, Random
Transmission range (m)	100, 250
Radio Propagation Model	Shadowing
Traffic model	CBR, TCP, mixed
Packets size (bytes)	512
Simulation time (s)	50, 400
Bandwidth	2Mbps
Routing	DSR

TABLE I
SIMULATIONS PARAMETERS

First, we compared our protocol with IEEE 802.11 DCF for the *ring* topology (Figure 2). The traffic consists of four CBR flows with packet size 512. Figure 3 and Figure 4 show the total packets received by nodes 1, 2, 4, 6 for the standard and our protocol, respectively. We can notice that our protocol leads to a higher degree of fairness then the IEEE 802.11 standard.

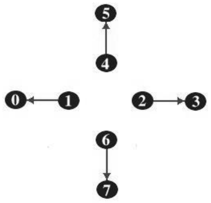

Fig. 2. Ring topology

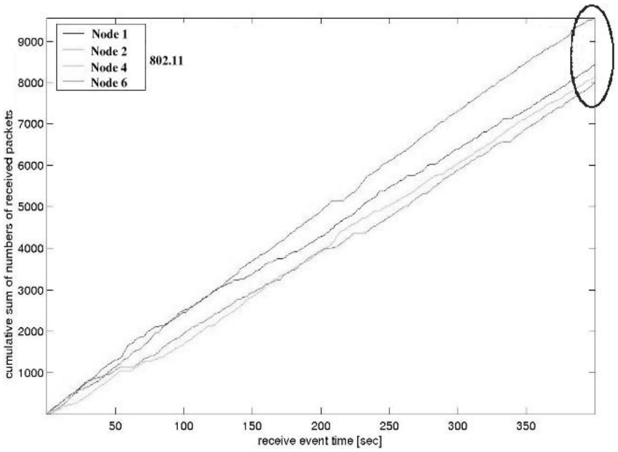

Fig. 3. IEEE 802.11, ring topology

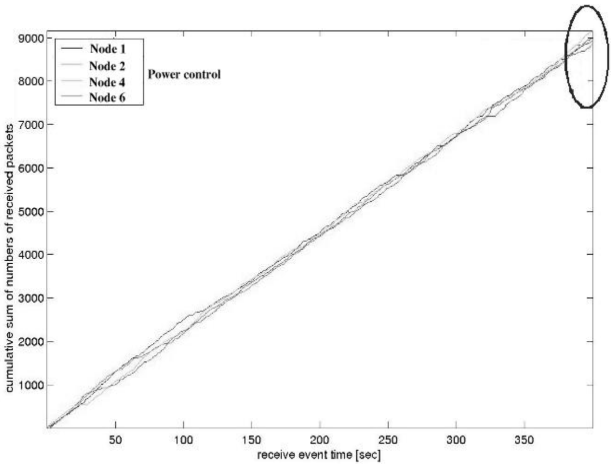

Fig. 4. Power control, ring topology

	Power control	802.11
Throughput (Mbps) ***Pkts Recv***	0.114560 *8502 (!)*	0.017095 *2440 (!)*
Delay (sec)	0.03624	0.6519
Pkts Loss	0.005723	0.212277
Throughput (Mbps) ***Pkts Recv***	0.069693 *7781*	0.050897 *6314*
Delay (sec)	0.05285	0.16768
Pkts Loss	0.048772	0.0886
Throughput (Mbps) ***Pkts Recv***	0.119048 *8908*	0.062599 *7675*
Delay (sec)	0.03298	0.0746
Pkts Loss	0.010156	0.045226
Throughput (Mbps) ***Pkts Recv***	0.110688 *8819*	0.04401 *6007*
Delay (sec)	0.01445	0.13928
Pkts Loss	0.009132	0.13221

TABLE II

SCENARIO: 1,2,3,4 RESPECTIVELY: TCP TRAFFIC

	Power control	802.11
Throughput (Mbps) ***Pkts Recv***	0.034883 *3084*	0.021969 *2695*
Delay (sec)	0.00311	0.0872
Pkts Loss	0.0083	0.16975
Throughput (Mbps) ***Pkts Recv***	0.03566 *3159*	0.019471 *2797*
Delay (sec)	0.01515	3.898403
Pkts Loss	0.045469	0.320982
Throughput (Mbps) ***Pkts Recv***	0.03392 *3594*	0.018366 *2673*
Delay (sec)	0.014628	2.7046
Pkts Loss	0.09508	0.313392
Throughput (Mbps) ***Pkts Recv***	0.02752 *3946*	0.017837 *2680*
Delay (sec)	0.072037	3.742521
Pkts Loss	0.14165	0.336145

TABLE III

SCENARIO: 1,2,3,4 RESPECTIVELY: CBR TRAFFIC

	Power control	802.11
Throughput (Mbps) ***Pkts Recv***	0.100346 *9324*	0.030749 *2861*
Delay (sec)	0.06591	1.45404
Pkts Loss	0.015394	0.249921
Throughput (Mbps) ***Pkts Recv***	0.072215 *9343*	0.018287 *2777*
Delay (sec)	0.10695	2.028767
Pkts Loss	0.026165	0.320969
Throughput (Mbps) ***Pkts Recv***	0.060367 *8770*	0.019081 *2948*
Delay (sec)	0.38888	3.58586
Pkts Loss	0.039468	0.305251
Throughput (Mbps) ***Pkts Recv***	0.059147 *7972*	0.015889 *2430*
Delay (sec)	0.33688	2.1896
Pkts Loss	0.064219	0.306257

TABLE IV

SCENARIO: 1,2,3,4 RESPECTIVELY: MIXED TRAFFIC

We have also simulated four different scenarios for CBR, TCP and mixed traffic for 25 nodes with 11 flows in a 500x500 area (in order to achieve high interference environments). Table II presents results for all scenarios for TCP traffic with packet size 512 bytes. Figure 5 and 6 show the packet loss for scenario 1 and 4 and Figure 7 depicts the throughput of our protocol (#) with respect to the standard (*****). In the first scenario the performance of the standard is really bad, because the total number of packets received by the nodes in the whole network is equal to 2440, where in case of the power control scheme the nodes have received more than 8000 packets. We can also notice that our protocol has a better throughput performance. The delay and packet loss is always much better as well. In Table III the results for four scenarios for CBR traffic are presented. Figure 8 and 9 show the throughput of the power control scheme compared to 802.11 for the first and second scenario. For clarity, we have indicated the range of the values of our protocol by means of dots. We can see that our protocol is stable and has a constant fluctuation between the consecutive values of the throughput. The standard behaves unpredictible, the variability is high and it never achieves a better performance then our protocol. Figures 10 and 11 present the delay of our protocol and the standard. We can also notice that the fluctuations of the delay are more stable

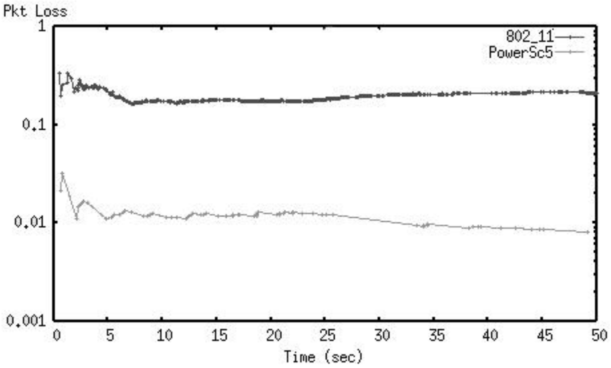

Fig. 5. Scenario 1: Packet Loss- 802.11 and Power control, TCP traffic

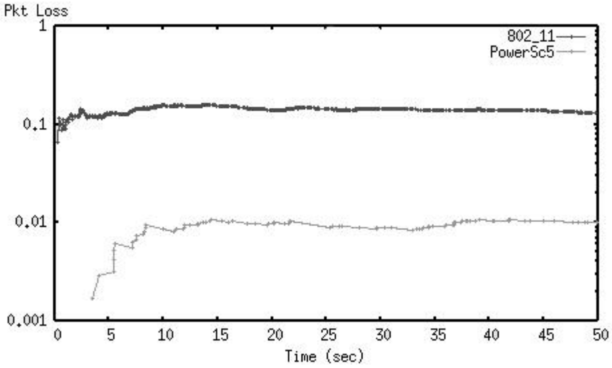

Fig. 6. Scenario 4: Packet Loss- 802.11 and Power control, TCP traffic

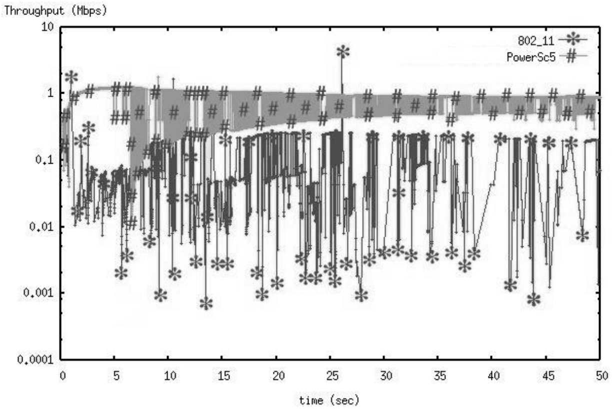

Fig. 7. Scenario 1: Throughput- 802.11 and Power control, TCP traffic

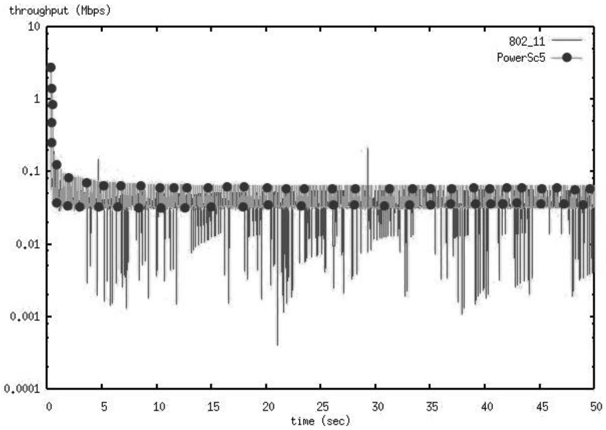

Fig. 8. Scenario 1: Throughput- 802.11 and Power control, CBR traffic

and lower than in the standard. Table IV shows the results for four scenarios for mixed traffic, CBR and TCP traffic. In these simulations the number of flows is equal to 22. We can easily notice that the standard can not handle such high interference level network, where our protocol manages to achieve a very good performance (with respect to the standard) thanks to power control. Figure 12 shows the performance of the throughput and Figure 13 compares the packet loss of the standard and the power control scheme.

V. CONCLUSION

In this paper we have presented the performance of a MAC protocol for ad hoc networks with a novel power control scheme added to the standard IEEE 802.11 DCF. Nowadays, according to the IEEE 802.11 the power control is not applied, just because ad hoc network does not take into account the variability of the transmission range of nodes. As we have shown through our simulations, the multihop wireless network topology can be controlled using different values of the transmission power taking into consideration the history of power changes. In future work, through the execution of many simulations (also mobile networks), we will try to find the optimal values of the transmission power with different fading effects with respect to the throughput for the whole network. We will also analyze the performance for different values of $nr\_of\_Neigh_{MAX}$.

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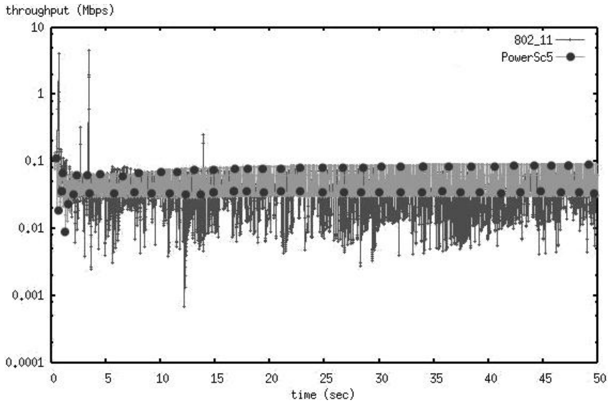

Fig. 9. Scenario 2: Throughput- 802.11 and Power control, CBR traffic

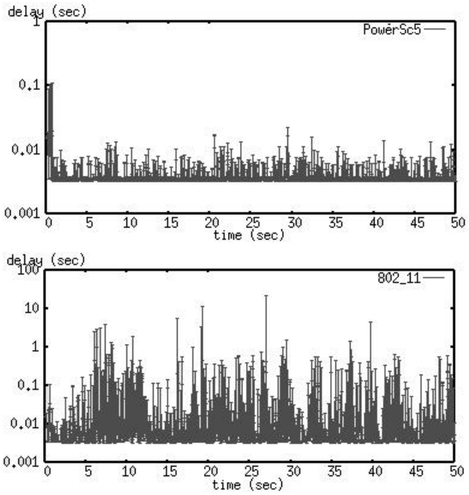

Fig. 10. Scenario 1: Delay- Power control (up), 802.11 (down), CBR traffic

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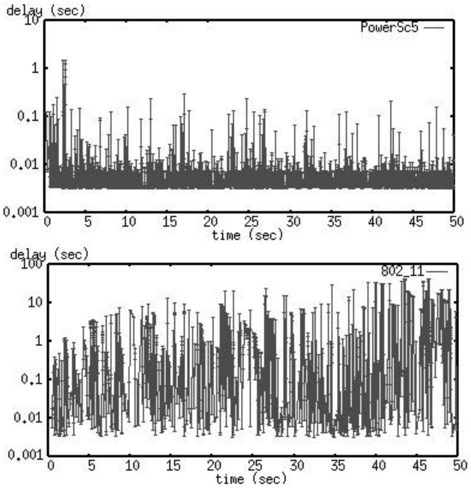

Fig. 11. Scenario 2: Delay- Power control (up), 802.11 (down), CBR traffic

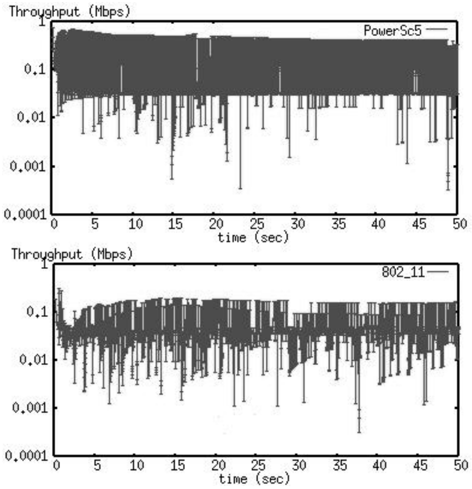

Fig. 12. Scenario 1: Throughput- Power control(up), 802.11 (down), mixed traffic

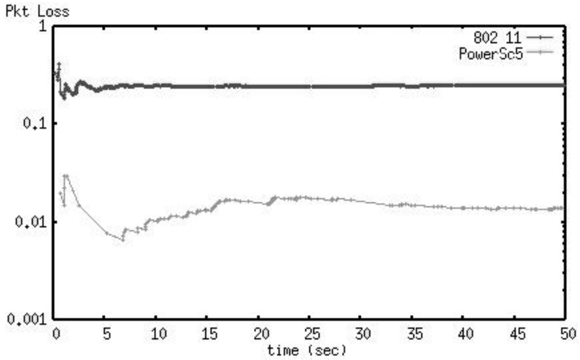

Fig. 13. Scenario 1: Packet Loss- 802.11 and Power control, mixed traffic