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QoS ENHANCEMENT IN MANET BY DIRECTIONAL POWER CONTROL

In this paper, the 4-Way Directional Power Control with Recoil Loop (4WDPCRL) protocol for power control of directional antennas is presented. We propose the scheme with using of control packets (RTS/CTS/DATA/ACK) for exchanging information about node's transmitted energy. Whenever the frame is received, the appropriate power for transmitted frame is computed. This information is stored together with updated information about position of node to the table. If a new transmission occurs, the node sends packet with updated information about position and appropriate power. The simulation results show that the throughput and energy consumption of the proposed protocol was improved compared to IEEE 802.11 MAC protocol with omni-directional antenna and DMAC protocol with directional antenna.

Keywords: *MANET, directional antenna, power control, IEEE 802.11.*

1. Introduction

One of the main targets in designing mobile ad hoc networks (MANET) is how to enhance the network throughput while maintaining low energy consumption for packet processing and communications. One approach how to increase throughput is to use directional antenna. With directional antennas, a transmitter can concentrate most of its power towards the destination and reduce interference to nodes in the vicinity. This leads to extended communication range, increased spatial reuse and less interference to other ongoing transmissions. However, to control this antenna the effective directional MAC protocol is needed. A lot of researches are engaged to design an effective directional MAC protocol [1 and 2]. However, most of them assume transmitting signal without any power control mechanism. Although directional antenna and power control by themselves can improve spatial reuse considerably, only when both are employed simultaneously the full potential capacity is realized [3 - 6].

In this paper, we propose a new MAC protocol called 4-Way Directional Power Control with Recoil Loop (4WDPCRL). This protocol uses a directional virtual carrier sensing (DVCS) mechanism [7] to effectively control the directional antenna. Moreover, the power control mechanism is used. If a new transmission occurs, the node sends control packets (RTS, CTS, ACK) and DATA packets to exchange information about the transmission energy. Whenever the frame is received, the appropriate power for its transmission is computed. This information is stored together with updated angle of arrival (AoA) information about a position of node to the neighbor table. This table includes every node in the network with actual information about position and appropriate power. If a destination node doesn't receive a RTS packet, the source node sets value of transmitting power to maximal transmitting level to re-establish the connection. This leads to increased spatial reuse, less interference to other ongoing transmissions and saving the energy.

This paper is organized as follows. The proposed directional power control MAC protocol is presented in Section 2. In Section 3 the proposed protocol in more details is presented. Section 4 presents simulation environment and simulation results and section 5 provides the conclusion.

2. The Proposed Directional Power Control MAC Protocol

Interference Estimation Using Analytical Model

Preliminaries

A flat-top model of a directional antenna for determining the interference is shown in Fig. 1, where R denotes the maximal permitted transmission range of node A, θ is the beam width of the main lobe. This model is simplified, since the side lobes are not used [8].

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Two types of interference result from the application of directional antennas: *direct* and *indirect interference*. All nodes outside the main lobe (grid in Fig. 1) are considered to be direct interference and may turn their directional antennas in any direction. All nodes inside the main beam of A within range R (grey region in Fig. 1) are considered to be indirect interference since they will refrain from transmission in the direction of node A, and they will not cause any direct interference to node A. These nodes are free to be engaged in any communication toward other directions.

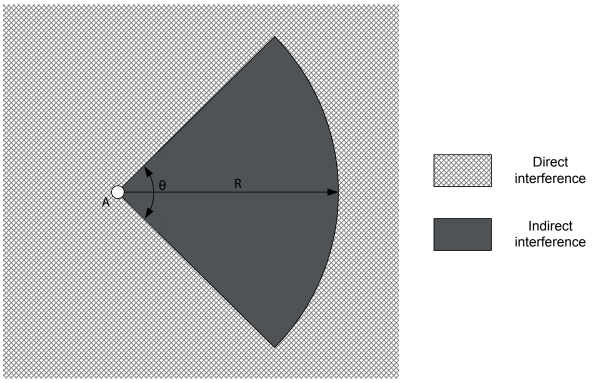

Fig. 1 Flat-top directional antenna interference region [1]

Directional interference model

Let P_t be the transmitted power, P_{th} receiver´s power threshold, h is the antenna height, α is the attenuation factor and G_m is gain of the main antenna lobe. Using a two-way propagation model, the exponential attenuation factor was set to 4. Then R is given by

$$R = \left(\frac{P_t G_m^2 h^2}{P_{th}} \right)^{\frac{1}{\alpha}}. \quad (1)$$

Those nodes which can directly interfere with A, may point their antenna to any direction with equal probability. As a result, the antenna gain of these nodes is a random variable given by G_l, i.e.

$$G_1 = \frac{\theta G_m}{2\pi}. \quad (2)$$

Now, we need to calculate the total amount of interference as perceived by node A. Consider the nodes inside the main beam of node A and at distances r and $r+dr$ from node A. Each node in this area is going to contribute to an interfering signal $I_1(r)$ and each node outside the main lobe of node A [r, $r+dr$] will contribute to an interfering signal $I_2(r)$. Values of $I_1(r)$ and $I_2(r)$ are given by

$$I_1(r) = \frac{P_t G_m h^2}{r^4}, r < R \quad (3)$$

$$I_2(r) = \frac{P_t G_m G_l h^2}{r^4}, r > R \quad (4)$$

Therefore, the total interference for node A is given by

$$I_{total} = \rho\theta \left(\int_0^R I_1(r) r dr + \int_R^\infty I_2(r) r dr \right), \quad (5)$$

where ρ is the uniform active node density, determined by the number of active nodes in the whole network divided by the area of distribution of all nodes in the network (nodes per square meter).

If the node with which node A is communicating is located at distance d, then the signal-to-interference ratio (SIR) at A will be given by

$$SIR = \frac{\left(P_t h^2\right) / d^4}{I_{total}}. \quad (6)$$

Power Control Mechanism

For the correct reception of messages by 4-way handshake (RTS/CTS/DATA/ACK), it is needed that power of received packet must be higher than P_{th}, where P_{th} is the minimum power threshold required to receive the packet correctly.

$$\begin{cases} P_{r-RTS} \geq P_{th} \\ P_{r-CTS} \geq P_{th} \\ P_{r-DATA} \geq P_{th} \\ P_{r-ACK} \geq P_{th} \end{cases}, \quad (7)$$

where P_{r_RTS}, P_{r_CTS}, P_{r_DATA}, P_{r_ACK} are values of the received power of RTS, CTS, DATA and ACK packets. In NS-2 simulator the value $P_{th} = Rx_{threshold}$.

To calculate the effective transmission powers P_{t_CTS}, P_{t_DATA}, P_{t_ACK}, $P_{t\_F\_RTS}$, the following equations are used

$$P_{t-CTS} = P_{t-RTS} - \left(P_{r-RTS} - P_{th}\right). \quad (8)$$

$$P_{t-DATA} = P_{t-CTS} - \left(P_{r-CTS} - P_{th}\right). \quad (9)$$

$$P_{t-ACK} = P_{t-DATA} - \left(P_{r-DATA} - P_{th}\right). \quad (10)$$

$$P_{t-F-RTS} = P_{t-ACK} - \left(P_{r-ACK} - P_{th}\right). \quad (11)$$

3. Four Way Directional Power Control with Recoil Loop

To explain the operation of the 4WDPCRL protocol, we use a simple scenario with only two nodes, where node A wants to send data to node B. The basic principle of the 4WDPCRL algorithm can be divided into the following five steps:

1. Step – Sending RTS packet

Node A first checks the information about the location of node B in the neighbor table. This information is estimated by using AoA or RSS (Received Signal Strength) mechanisms. However, this information is not obtained at the beginning of the transmission and, therefore, RTS packet is sent by using omnidirectional antenna. Before node A will transmit the packet, it checks the information about value of transmission power for efficient packet transport to node B from previous transmission. This information is not obtained at the beginning, so RTS packet is sent by using the maximum power P_{max}. Information about transmission power $P_{t\_RTS}=P_{max}$ is encapsulated inside the RTS packet and also it is saved to the table. The flow graph of sending RTS packet is shown in Fig. 2.

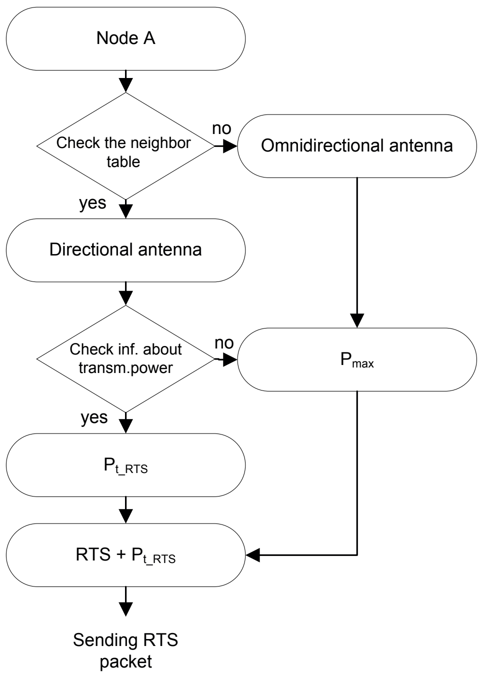

Fig. 2 Sending RTS packet

2. Step – Receiving RTS packet and sending CTS packet

Node B receives the RTS packet if the (7) condition is satisfied. If not, the packet is discarded. Node B records the information about the location of node A into the neighbor table, depending on fact which sector of the antenna received the maximum level of signal. Subsequently, the node B measures the value of received power P_{r_RTS}. Node also "knows" the value of which RTS packet was sent (value is encapsulated in the RTS packet). Based on information about P_{t_RTS} and P_{r_RTS}, node B computes the value of the effective transmitting power P_{t_CTS} for CTS packet by using (8). This value is encapsulated in the CTS packet and saved to the table. The node B then sends directional CTS packet using (8). The flow graph of receiving the RTS packet and sending CTS packet is shown in Fig. 3.

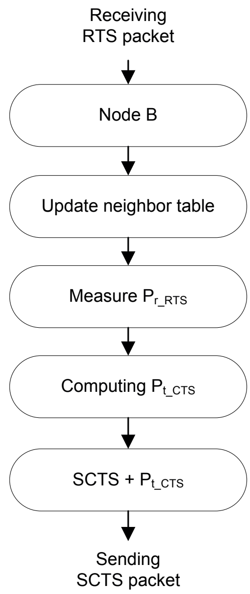

Fig. 3 Receiving RTS packet and sending CTS packet

3. Step - Receiving CTS packet and sending DATA packet

4. Step - Receiving DATA packet and sending ACK packet

Both steps are the same as the previous one, so only flow graphs are shown in Figs. 4 and 5.

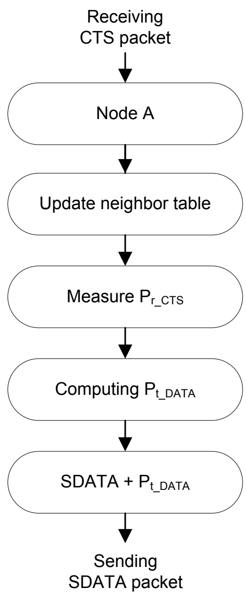

Fig. 4 Receiving CTS packet and sending DATA packet

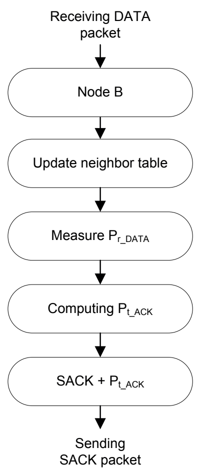

Fig. 5 Receiving DATA packet and sending ACK packet

5. Step - Receiving ACK packet and computing transmission power for future transmission

The first part of this step is the same as the previous ones. The second part is different - based on information about P_{t_ACK} and P_{r_ACK}, node B computes the value of the effective transmission power $P_{t\_F\_RTS}$ for future possible communication using (11). This information is stored in the table as the last known value of transmission power for node B. If the new transmission occurs to the same node (in this case to node B), the packet is transmitted with updated effective value of transmission power $P_{t\_F\_RTS}$ (11). This leads to loopback creation between the last and future transmission. If the destination node (B) doesn´t receive RTS packet when using the new transmission power value, the source node (A) automatically sets the output value $P_{t\_RTS} = P_{max}$ to restore the connectivity. The flow graph of receiving ACK packet and computing transmission power for future transmission is shown in Fig. 6.

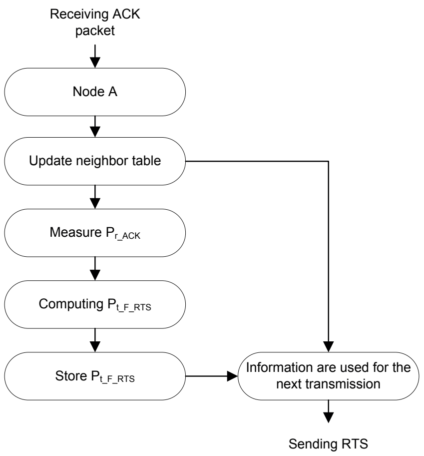

Fig. 6 Receiving ACK packet and computing transmission power for future transmission

4. Performance Evaluation

Simulation Setup

The NS-2 simulator was used to evaluate the performance of our proposed protocol scheme. We compared the proposed power control scheme with IEEE 802.11 MAC (omni-directional antenna) and D-MAC (directional antenna) schemes. The directional antenna is used as a switched beam antenna (divided to 12 antenna sectors) with a flat top radiation pattern. The simulation model consisted of 30 wireless nodes randomly placed in an area of 1000 x 1000 m. NS-2 mobility model was used, where nodes' speed was changed from 0 to 5 m/s with 1 m/s step. As a traffic model, 10 Constant Bit Rate (CBR) flows with the packet size of 512 bytes were used. The packets generation rate (number of packets per second) was randomly changed. Simulation parameters are summarized in Table 1.

Simulation parameters Table 1

Parameter	Value	Parameter	Value
Test area	1000x1000 m	Antenna type	Omni-directional
MAC protocol	IEEE 802.11		Directional
	D-MAC	Directional beamwidth	30°
	4WDPCRL	Transmitter power	281.8 mW
Propagation model	Two ray ground	Rxthreshold	-89 dBm
Simulation time	200 s	Packet size	512 bytes
Initial energy	200 J	Traffic type	CBR (UDP)

As the routing function is not allowed, nodes that want to start communication with each other were located in their own communication range.

Results and Analysis

Figure 7 shows simulation results of average network throughput for 10 data flows, where speed of nodes was changed. The lowest value of average throughput for all speeds was achieved by using IEEE 802.11 MAC protocol with omni-directional antennas. For 0 m/s the proposed protocol enhanced throughput about 66.7% compared to IEEE 802.11 MAC protocol and for 5 m/s the enhancement was up to 58.4%. This enhancement in network throughput was achieved by increasing the number of simultaneous transmissions by minimization of interference.

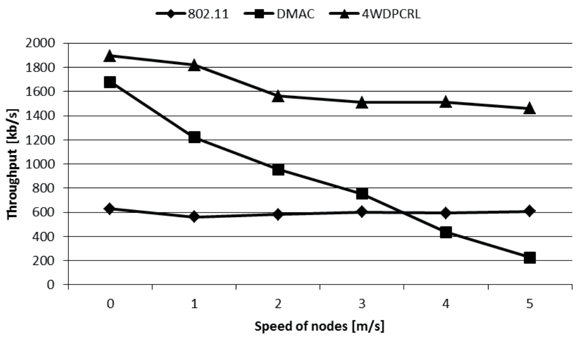

Fig. 7 Average values of throughput for different MAC algorithms and for 10 data flows.

Figure 8 shows the values of packet error rate (PER) for three different MAC protocols. From the results we can see that the best result was reached by 4WDPCRL protocol. This enhancement in PER is achieved by minimized interference.

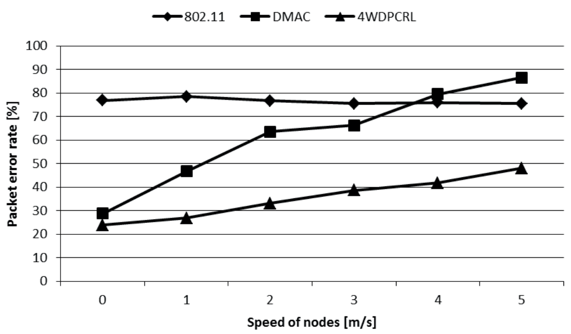

Fig. 8 Average values of packet error rate for different MAC algorithms and for 10 data flows

The average energy consumption per node is shown in Fig. 9. The results show that the highest values of energy consumption were reached with IEEE 802.11 MAC protocol. The best value was again achieved by using 4WDPCRL protocol. The enhancement in the energy consumption is achieved by integration of a power control scheme.

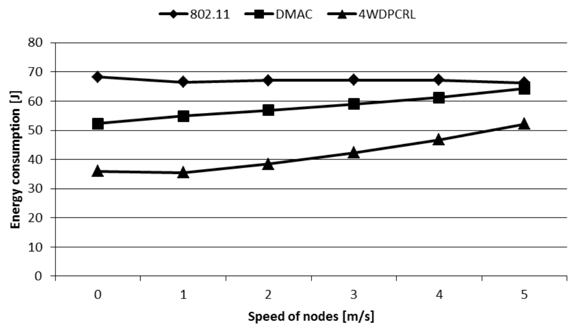

Fig. 9 Average values of energy consumption per node for different MAC algorithms and for 10 data flows

The average values of energy consumption of all nodes together are shown in Fig. 10. The results show that the highest value of energy consumption of all nodes was reached with IEEE 802.11 MAC protocol with omni-directional antennas, which was expected. More important improvement in energy consumption is in comparison of both directional MAC protocol schemes, where 4WDPCRL protocol outperforms DMAC protocol mainly in lower mobility. This enhancement in the energy consumption is achieved by integration of a power control scheme.

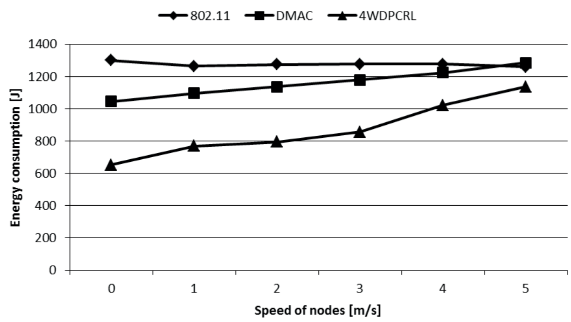

Fig. 10 Average values of energy consumption of all nodes for different MAC algorithms and for 10 data flows

5. Conclusions

In this paper, a new power controlled directional MAC protocol for MANET networks, named 4-Way Directional Power Control with Recoil Loop (4WDPCRL) was proposed. At the beginning of the transmission only the first RTS packet is transmitted omni directionally and with maximal power, other packets are sent directionally and with effective transmission power used. By using loopback, the interference at the start of the new transmission between the same nodes was optimized because both nodes had already included location information and information about effective transmitter power. This leads to minimizing the interference, to improved spatial reuse and also to saving energy, which is very limited in MANET networks.

The rest of the paper gives the comparison of the proposed 4WDPCRL protocol with both widely used DMAC and IEEE 802.11 MAC protocols. On the basis of simulation results we can say that our proposed protocol outperforms both widely used IEEE 802.11MAC and DMAC protocols in chosen quality of service parameters - throughput and energy consumption.

Acknowledgment

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