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Multipath Routing with Adaptive Carrier Sense for Video Applications in Wireless Ad-hoc Networks

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Introduction

Video streaming over wireless ad-hoc networks containing mobile nodes is a quite complicated task because existing transport and routing protocols are not well suited for such task. Video transport is very sensitive to packet delay and packet loss, but in mobile ad hoc wireless networks (MANET) links could be frequently interrupted due to node mobility, interference, channel fading etc. Use of MANETs is increasing and demand for multimedia services is expected to grow significantly in future. Therefore development of robust coding and transport methods maintaining QoS, as well as efficient routing protocols is important.

In 802.11 standard MAC level transport protocol uses Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) method. This collision avoidance method as a side effect may prevent possibly successful data transmission events as well. This degrades delay time and data transmission rate which are very important parameters to maintain QoS in video streaming.

To improve network throughput there are made attempts to use adaptive algorithms to update a Carrier Sense threshold values after any change of network topology or other circumstances [1, 2]. Some feedback from physical or network layers is needed to evaluate situation and update threshold value. Interference level can be monitored and communicated between neighboring nodes to choose some optimum Carrier Sense (CS) threshold value which is a minimum value from all offered values [1]. Algorithm K-APCS [2] is seeking for optimum CS using throughput and frame loss rate as criteria. 802.11k radio resource measurements are used to obtain information for throughput and frame loss calculation. Still adaptive SC is not an ideal solution because a rate of packet collisions may increase.

To improve robustness of video coding it is possible to split one video stream in multiple parallel sub-streams. Multiple description coding (MDC) method [3] creates robust representations of video data streams suitable for transmission over the networks suffering from packet loss. Video can be decoded from any of parallel sub-streams (descriptions). Quality improves if all streams could be received and decoded.

There are also some other Multistream Video Coding (MVC) methods [4-7] used for MultiPath Transport (MPT) of video streams.

In this paper we attempt to introduce multi-path routing combined with adaptive carrier sense range thus minimizing mutual interference caused by neighboring nodes still keeping low level of collision rate.

In first section are analyzed main methods for video signal separation in multiple streams. In following two sections is described tuning of Carrier Sense to optimum threshold and how to combine it with multipath routing. In fourth section are presented simulation results and discussion.

Video Separation in Multiple Streams

Video transport (streaming) over mobile ad hoc wireless networks is very challenging because links are very unstable and it is difficult to maintain QoS. There are several approaches attempting to maintain QoS in video transport (streaming) in MANETs.

Multipath transport provides an extra degree of freedom in designing error resilient video coding and transport schemes. The general architecture for multi path transport of video streams [4] is presented in Fig. 1. At the sender site, the raw video is compressed by a multi-stream encoder into *M* streams. Then the streams are partitioned and assigned to *K* paths by a traffic allocator. These paths are maintained by a multipath routing protocol. When the flows arrive at the receiver site, they are first put into a re-sequencing buffer to restore the original order. Finally, the video data are extracted from the re-sequencing buffer to be decoded and displayed.

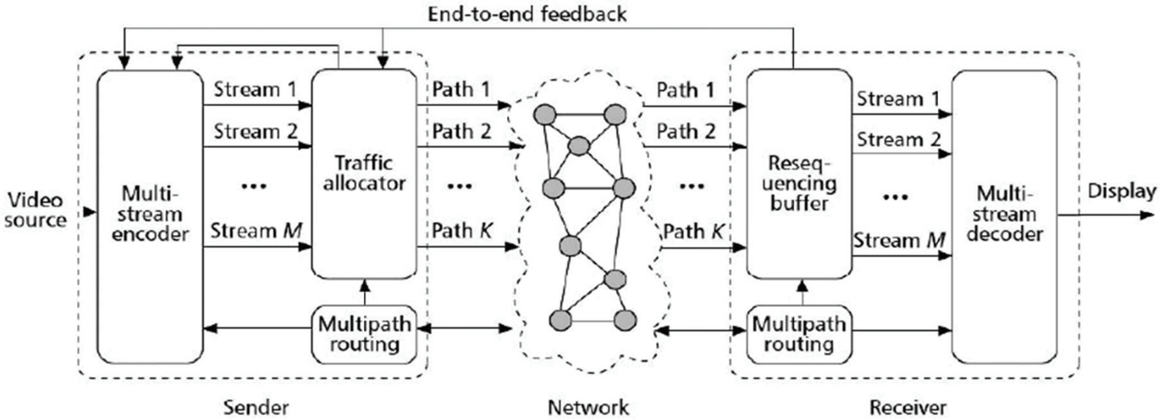

Fig. 1. General architecture for multipath transport of video streams [4]

Several Multistream Video Coding (MVC) methods are used with MPT. The video coder must generate substreams in a way that the loss in one substream does not adversely affect the decoding of other substreams.

In the H.263+ standard Video Redundancy Coding (VRC) all odd frames are sent to path 1 and all even frames are sent to path 2 [5]. This method requires significantly higher bit rates and error propagation still exists within frames in the same path.

Another way of generating multiple streams is by using layered video coding, which encodes video into several layers. The base layer (BL), which includes the crucial part of the video frames, guarantees a basic display quality. Enhancement layer (EL) data correctly received improves the video quality. BL packets are better protected with FEC (Forward Error Correction) or ARQ (Automatic Repeat reQuest) [6]. When combined with MPT, it is desirable to transmit the BL substream on the best route. Without the BL, video frames cannot be reconstructed sufficiently. If link transporting BL substreem fails, then QoS is seriously affected.

In Multiple Description Coding (MDC) method [3] multiple equally important streams are generated, each giving a low but acceptable quality. A high-quality reconstruction is possible from all bit streams together, while a lower, but still acceptable quality reconstruction is achievable if only one stream is received. Encoder recovers lost information of one substream, using information carried in other correctly received substreams.

The new adaptive-Multipath Multimedia Dynamic Source Routing (a-MMDSR) protocol includes cross-layer techniques which improve the end-to-end performance of video-streaming services over IEEE 802.11e [7,8]. The mapping of different packets into each one of the four Access Categories of the IEEE 802.11e MAC starting with the high priority packets and ending with low priority packets in the forth category.

As Fig. 2 depicts, the most important frames of the coded video flows (I frames) are sent through the best available path. P frames are sent through the second best path and B frames through the third one. If only two paths were available, I frames would be sent through the best one, and P and B frames through the other one. In case of a unique available path all types of frames would be sent through this path.

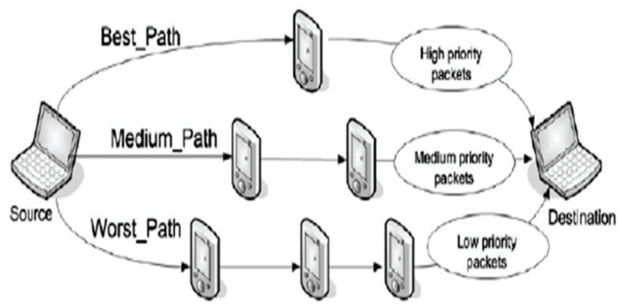

Fig. 2. Multipath scheme using three paths [8]

The a-MMDSR routing protocol not only has the ability to find long-living paths, but also it proactively starts to search alternative paths before the actual breakage of the current paths, using a mathematical model to estimate the path error probability of the forwarding routes.

Physical carrier sense threshold tuning

Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) method is used in 802.11 standard MAC level transport protocol. This section covers analyses of physical carrier sense (PCS) mechanism, its negative side-effects and possible improvements to increase the network throughput.

In this analysis and later simulation simple two-ray ground reflection radio propagation model is used. For this model the received power at distance d could be calculated from formula

$$\boldsymbol{P_r(d)} = \frac{\boldsymbol{P_t}}{\boldsymbol{d^4}}, \tag{1}$$

here P_t is transmitter power.

The receiver can receive a packet if received signal $P_r(d)$ is greater than receiver sensitivity P_R and Signal-Noise-Interference Ratio (SNIR) is above threshold S_0 [1]:

$$\begin{cases} \boldsymbol{P_r(d) \geq P_R}, \\ \frac{\boldsymbol{P_r(d)}}{\boldsymbol{P_N + \sum_i P_r(d_I)}} \geq \boldsymbol{S_0}, \end{cases} \tag{2}$$

here P_N is background noise and $\sum_i P_r(d_I)$ is sum of signal power received from interfering sources – other transmitting nodes in network.

S_0 depends on data rate and appropriate modulation scheme used.

To reduce number of cases when due to interference SNIR < S_0, physical carrier sense is used. It prevents node from new transmission that could cause interference able to disturb ongoing transmission. Distance in which channel is sensed depends on physical carrier sense threshold (PCST). If signal strength sensed at transmitter side is greater than PCST, transmission is held up.

Although PCS helps to prevent possible collisions, often its range is chosen too large and therefore some possibly successful transmissions are held up as well. In Fig.3 is illustrated example with ranges that influence data transmission between nodes Tx to Rx which are placed at a distance d. Here d_R is reception range - distance in which receiver can receive packet from transmitter and d_I is interference range - within such distance from receiver any single transmitter can interrupt ongoing transmission. Distance d_I can be calculated from eq.1 and 2 considering $P_N << P_r(d_I)$

$$d_I \approx d \cdot \sqrt[4]{S_0}. \quad (3)$$

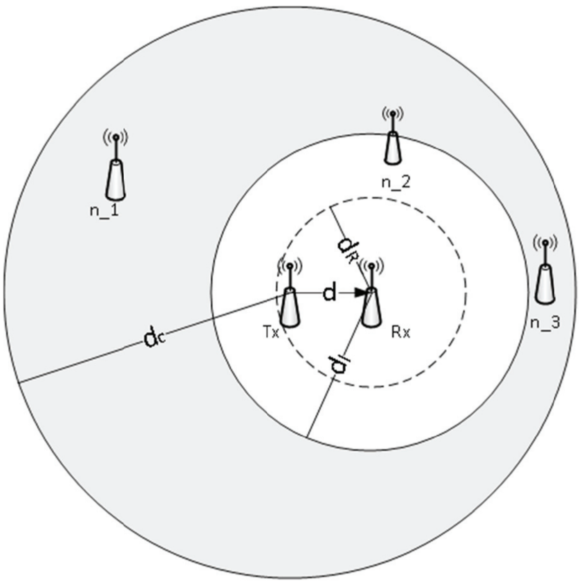

Fig. 3. Interference, reception and PCS ranges

From Fig. 3 we can see that, if node 3 or node 1 has occupied channel, then Tx is blocked, even though these nodes don't create interference to receiver Rx. The same happens vice versa – nodes in CS range d_c are affected by ongoing transmissions from transmitter Tx. If we denote the carrier sense zone as area A_C and the interference zone as area A_I, then nodes inside the area $(A_c - A_I)$, which is colored in gray, are unnecessarily blocked from transmitting. That may considerably degrade network performance.

From previous paragraph follows, that it is useful to decrease PCS range to a level that protects Rx from collisions, but do not unnecessarily block distant node operation. It is easy to notice that d_C can be safely decreased to a range that excludes node 3 but still cover Rx interference area A_I.

However even this is not the most optimal range because still there remains node which is unnecessarily blocked. Node 1 is so called exposed terminal, as "exposed to blocking" due to SC mechanism. We can decrease CS range even more, but there is a risk that whole interference area is not covered. In Fig. 4 risk area is colored in black. If there is any transmitting node (hidden node) in the risk area, there will be high probability that packet collisions will be observed. Since topology in Figure 4 doesn't have nodes in that area, it is risk-free because only node (No 2) that could interfere with Rx is still in CS range.

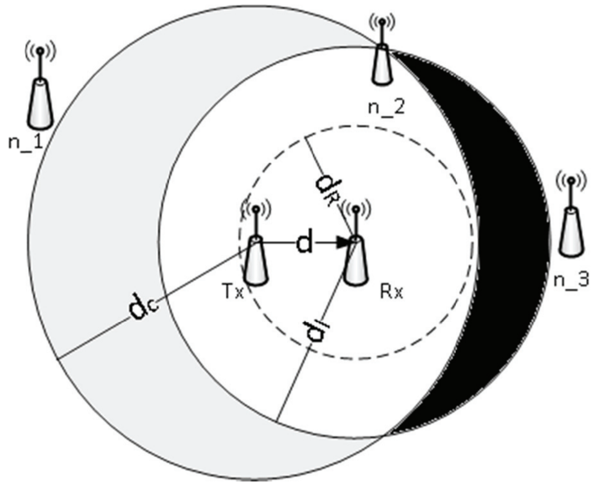

Fig. 4. PCS range don't cover interference area

Interference may also come from more distant sources and sum up at receiver. Such interfering nodes don't even need to be in the interference area d_I around Rx.

There are cases when it is worth to leave some interfering nodes but in same time to decrease number of blocked nodes what can result in better overall network throughput. This balance is often called trade-off between hidden and exposed nodes. In this case PCST adjustments should be done taking into account network performance metrics. In work [1] it was proven that optimal CS value could be calculated from the formula

$$P_C = \frac{P_r(d)}{S_0}. \quad (4)$$

CS tuning combined with multipath routing

Finding of best paths in multipath video transport may not be easy because interference and exposed terminal problem must be taken into account. Routing protocol must ensure that nodes belonging to one path don't interfere with nodes from other one. It can be achieved if distance between every two nodes belonging to different paths is greater than interference range $(d_p \geq d_i)$. While preventing local interference in individual path PCS may cause exposed nodes in other path, thereby intensify inter-path interference.

In Fig. 5 is presented situation when paths don't interfere mutually but still there is a disturbance caused by PCS mechanism. Nodes 4, 5, 6 belonging to path 2 are blocked while transmission is taking place between Tx and Rx.

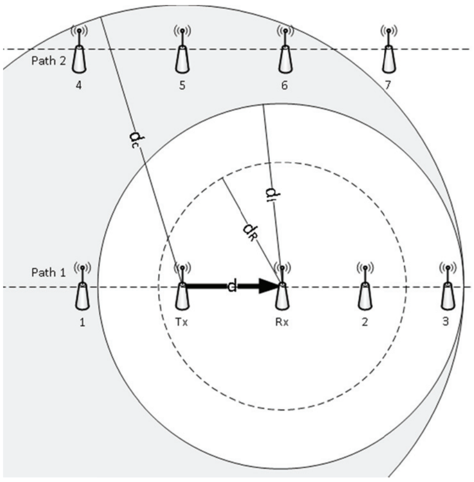

Fig. 5. PCS caused disturbance

To avoid such situations there are two options: either make path selection by taking into account both interference and PCS range, as it is done in routing protocols that are based on link quality estimation, or make path selection using local per node SNIR estimations and then adjust PCST so that inter-path disturbance is avoided as much as possible.

First solution is easier to implement, but it may fail in real life situations. In some cases it could be difficult to find mutually disjoint paths because of necessary distance to prevent PSC disturbance. Many interference aware multi-path routing protocols work is such way.

In this paper we are going to analyze second option where PCST is being adjusted after path selection. This method aims to find compromise between inter-path disturbance by PCS mechanism and interference created by hidden nodes locally in each separate path.

As we see from Fig. 6, if PCS is adjusted so that there are no blocked nodes in path 2, then collision probability increases because node 3 located in Rx interference area is not "heard" by Tx anymore. How much it will influence network performance and will it tolerate collision increase is analyzed in experimental part through network simulations.

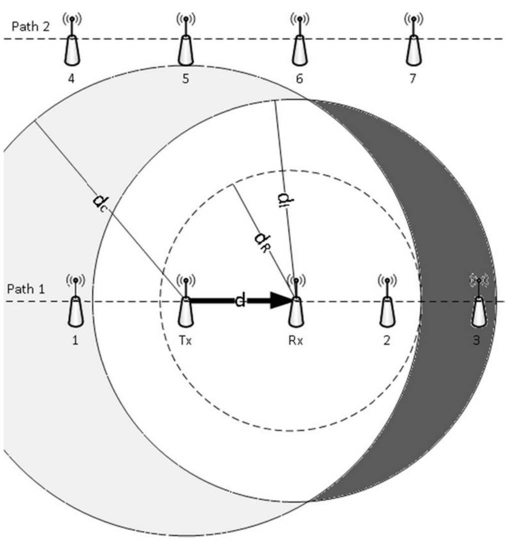

Fig. 6. Interference and PCS disturbance free situation

Simulation results and discussion

In this section we are continuing analyses on PCS and through simulations will show its impact on channel throughput. We will show that appropriate tuning such parameter as PCS threshold may help to improve throughput. Moreover, separating video streams and by sending them over disjoint paths (inference and exposed nodes free path) may help to improve it even more. In our experiments we will send several video streams in opposite directions. It is quite similar to videoconferencing applications and complicates data transmission because data packets and MAC acknowledgments travel in both directions.

To evaluate how PCS threshold level influences data transport over network, several performance metrics could be used: throughput, packet end-to-end latency and jitter, collision rate.

Since we concentrate on video stream transport further we will use maximum bit rate metric expressed as bits per second. This metric characterizes maximum video quality that could be achieved in a network. Maximum bit rate is limit which shouldn't be exceeded for one video stream. In earlier paper [9] was observed that if stream's bit rate exceeds certain limit, then packet end-to-end latency and jitter grows rapidly because network becomes overloaded.

Another performance metric used is MAC collision rate which directly influences metrics discussed above and best of all characterizes effectiveness of collision avoidance mechanisms. It is measured as a number of dropped packets per second by all nodes due to collisions in MAC layer.

For modeling Network Simulator 2 (NS-2) [10] is used. Network topology for simulation consists of 10 static nodes (Fig. 7). There are two possible paths to send traffic between nodes 0 and 5, each going through four intermediate nodes. Distance between nodes in each path is d = 40m and transmission distance d_R is set to 50m. Distance between paths d_{path} = 60m.

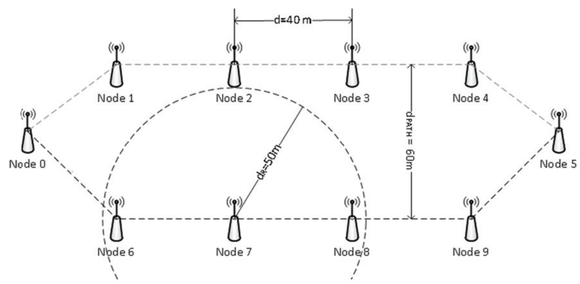

Fig. 7. Network topology

We assume that interference range d_I is equal to reception range of receiver d_R. Transmitter power P_t=0.1 W, receiver sensitivity P_R=1.6e-8 W. In this experiment interference from other nodes in the network is not taken into account.

To simulate videoconference consisting of two bidirectional video streams, constant bit rate data packets are generated and sent over UDP transport protocol. Data packet size is 250 bytes.

The maximum bite rate and collision rate was measured while varying the sensing threshold expressed as a sensing range. From (1) PCS range can be linked to PCS threshold PCST thorough formula

$$d_c = \sqrt[4]{\frac{P_t}{P_{PCS}}}. \qquad (5)$$

In *the first scenario* both streams are sent over joint path as shown in Fig. 8.

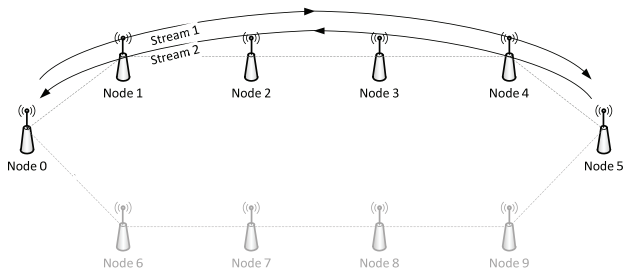

Fig. 8. Transmission of video streams over joint path

Simulation results are shown in Fig. 9 and Fig. 10.

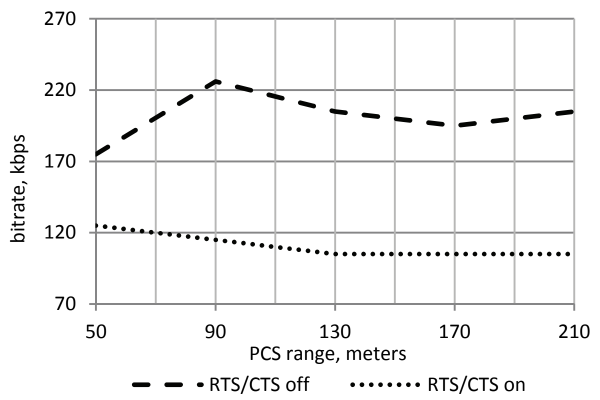

Fig. 9. Maximum bitrate per stream versus PCS range

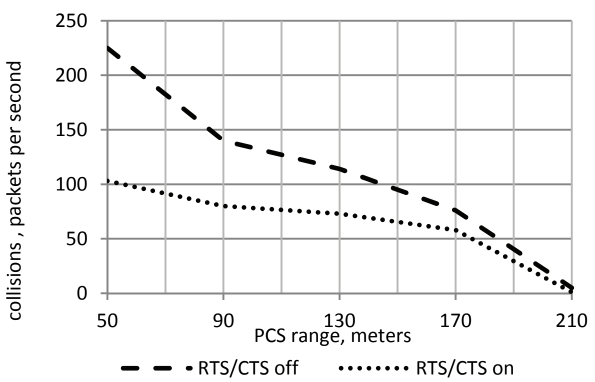

Fig. 10. Packet collision rate versus PCS range

In Fig. 9 we can see that RTS/CTS packet exchange notably degrades network performance because it causes additional load by occupying channel. Although RTS/CTS reduces number of collisions it can't eliminate them fully because still there remain hidden nodes.

As we can see in Fig. 9 there is one optimal PCS range when throughput is the largest. At this point trade-off between hidden and exposed nodes is reached. In our experiment that's the CS range which covers two neighbors in radius (90 meters).

As it was expected MAC collision rate decreases if we increase CS range and reaches 0 when all nodes are covered (Fig.10).

In *the second scenario* each stream is sent separately (Fig 11). In such way the load on forwarding nodes located between 0 and 5 should be decreased. Drawback is that still there remain bottlenecks at the ends of paths because nodes 0 and 5 must handle both streams. As it was presented in previous section, multipath approach won't give any benefit if paths interfere mutually or PCS mechanism disturbs (blocks) nodes from other paths. Two paths must be maximally disjoint and RTS/CTS exchange is switched off. Simulation results are summarized in Fig. 12 and Fig. 13.

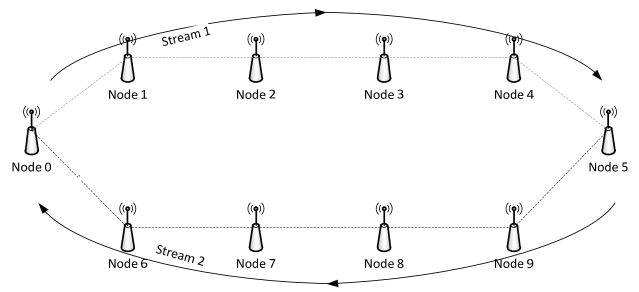

Fig. 11. Transmission of video streams over separate paths

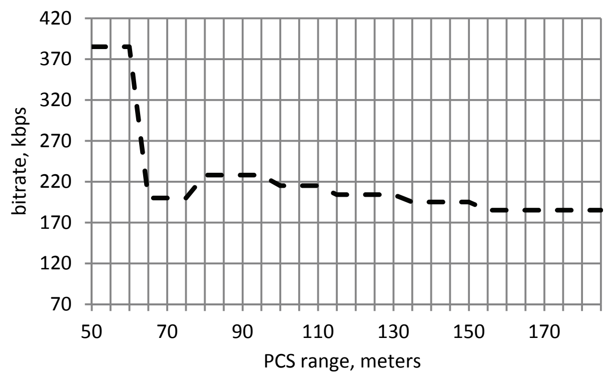

Fig. 12. Maximum bitrate per stream versus PCS range

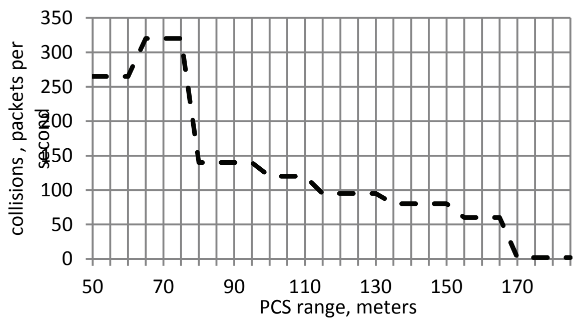

Fig. 13. Packet collision rate versus PCS range

Results show that the maximum throughput could be achieved at the smallest PCS range, thus when number of exposed nodes is the smallest. Graph is a step-like because all nodes are arranged regularly. Second peak is at ~80-90 m range when locally per path the optimal PCS range is reached which we observed also in previous scenario with joint path.

The highest collision rate is reached at PCS range 65-75m when inter-path disturbance starts. Though collision rate is high network tolerates it and overall performance increases.

Conclusions

Multipath routing may be used to increase network throughput and QoS for video applications in MANETs, if paths are properly selected to minimize mutual interference and other disturbance. Analysis show that using CSMA/CA protocol best results could be achieved with RTS/CTS switched off and adjusted Carrier Sense (CS) threshold level.

It is proposed to combine multipath routing with adaptive CS tuning. Path is selected taking into account interference and then CS range must be dynamically adjusted so that inter-path disturbance is prevented. That would allow decrease the distance between paths, thus making path selection easier. Results of the network simulation with NS2 show, that such approach may increase network throughput by 60% if compared to single path data transfers.

Further more detailed investigation is needed on how to implement this approach in routing protocols to arrange adaptive tuning.

Acknowledgements

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Dėl nepritaikytų transporto ir maršrutizavimo protokolų tiesioginiais bevieliais tinklais vaizdo įrašus peržiūrėti yra keblu. Straipsnyje pateikiamas daugiakelis maršruto taikymas, sumažinantis gretimų mazgų susidūrimą. Il. 13, bibl. 10 (anglų kalba; santraukos anglų ir lietuvių k.).