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Impact of Physical Carrier Sense Range on Network Throughput in Wireless Ad-Hoc Networks

Lauris Cikovskis[1], Ilmars Slaidins[2], [1-2]*Riga Technical University*

Abstract. **In the wireless ad-hoc networks the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) protocol may cause inter-node interference, especially at higher data rates. To increase network throughput, the simultaneous distribution of data over multiple paths can be used. However this method needs more experimental analyses to prove its effectiveness. In this paper effectiveness of multi-path method was investigated comparing results of simulation and experiments in wireless network testbed. The results confirm that overall network throughput does not increase or increase slightly if nodes of two paths mutually interfere due to Physical Carrier Sense mechanism.**

Keywords: **wireless ad-hoc networks, multi-path transport, CSMA/CA, Physical Carrier Sense.**

I. INTRODUCTION

Use of wireless ad-hoc networks is increasing and demand for multimedia services is expected to grow significantly in future. In a whitepaper [1] published by Cisco Systems there is a forecast that mobile data traffic will decuple in the next 4 years reaching 6.3 Exabyte per month and 66% of the traffic will be generated by mobile video applications. That will put much stress on the existing wireless infrastructures. Wireless ad-hoc networks are one of the solutions to decrease load in conventional wireless networks by offloading some data traffic to it. Therefore development of robust video coding and transport methods maintaining QoS, as well as efficient routing protocols, is important.

It is well known that 802.11MAC level protocol Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) is not well suited for wireless ad-hoc networks because of hidden and exposed nodes [2]. At higher data traffic intensity, CSMA/CA may cause inter-node interference that limits channel throughput and leads to high packet loss and degradation of overall network performance.

There are several methods used to cope with the problem such as adaptive physical carrier sense mechanism [2, 3], multi-path transport [4, 5]. Also radio resource management (e.g. use of directional transmission, use of separate frequency channels) could be a possible solution. In the multi-path transport method video is distributed and transported over multiple paths, thus minimizing load on every single path and increasing total throughput. However, multi-path transport also suffers from the CSMA/CA. Interference between nodes of two paths (inter-path interference) is possible therefore method's effectiveness strongly depends on a radio disjoint path selection. Until now this problem has been investigated mainly using computer simulation [2,4,5].

In this paper experimental results of investigation of the CSMA/CA impact on method's effectiveness are presented and compared to simulation results. For this purpose wireless network testbed and experiments performed with it are described here. Simulations of the same network configuration in the same conditions are provided for comparison.

In the first section we give insight into CSMA/CA protocol and its shortcomings as well as a survey of possible solutions of this problem. In the second section the wireless network testbed is described. In the last section impact of physical carrier sense to network throughput is analysed. Tests are performed both in simulation environment NS2 and wireless network testbed. Simulated end experimental results are compared.

II. BACKGROUND

A. Physical Carrier Sense and shortcomings

The CSMA/CA protocol was designed to reduce the collision probability between multiple nodes accessing a medium. A collision occurs at a receiver side if it receives packets simultaneously from multiple sources. Physical carrier sensing at transmitter side is performed to avoid such situation. When node wants to transmit, it senses the allocated frequency channel by monitoring RF signal level. If transmission by another node is sensed, transmission is deferred. Distance in which an eventual interference in the channel is sensed depends on physical carrier sense threshold (PCST).

Although PCS method helps to prevent collisions, it may defer possibly successful transmissions as well. Such situation is possible if PCST is too small (sensed range is too large) and therefore some nodes are exposed from transmitting even if they don't interfere with receiver. This is also known as exposed station problem [6] presented in Fig.1.

Fig. 1. Exposed station problem

If node 3 wants to send data to node 4, transmission will be deferred because at the same time node 2 transmits data to node 1. If transmission is deferred, data packet must wait in queue, thus increasing delay and decreasing throughput. This effect is very harmful for video applications where high network throughput and low latencies are important.

On the other hand PCST shouldn't be chosen too large (sensed range too small) otherwise a number of collisions will increase because of hidden nodes. This is known as hidden station problem [6]. For example (Fig.2), if node 3 doesn't hear that node 1 is sending data to node 2 it may start transmission to node 4. Possibly a collision will happen because node 2 receives signal both from node 1 and node 3.

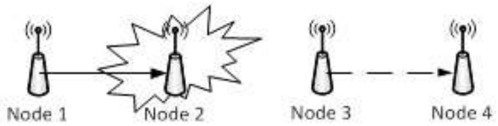

Fig. 2. Hidden station problem

Collisions are harmful for TCP traffic because every lost packet results in decreased transmission speed. Usually a trade-off between hidden and exposed nodes is sought to set PCST for best performance.

B. Adaptive Physical Carrier Sense

To avoid exposed station problem and thus increase network throughput, adaptive PCS mechanism could be used to tune PCST after every change in network topology, thus minimizing a number of nodes deferred from transmitting [2,3]. In [3] adaptive PCST is proposed based of SNIR measurements. RF interference level is monitored at each node and communicated between neighbours to choose some optimum threshold value which is a minimum value from all offered values.

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.

C. Multi-path routing

Multi-path routing is another approach to avoid limitations created by PCS. Instead of using one path, video traffic can be sent over multiple paths, thus distributing load. However, as pointed out in [7], such approach works only if paths are radio disjoint. It means that paths must be selected so that there is no mutual RF interference between them otherwise if node of one path senses ongoing transmission in other path, transmission is still deferred. Such phenomenon is called route coupling.

Multi-path routing effectiveness has been analysed in [5]. The authors compare throughput of single and multi-path routing conditions through NS2 simulations. The results showed that if compared to single path, two high-interfering paths could increase throughput only by 12% but low-interfering paths about 65%.

Inter-path interference can be reduced if multi-path routing is used together with adaptive PCST. In our previous work [4] we proposed method where PCST is dynamically adjusted after path selection so that inter-path interference is prevented. That would allow decreasing the distance between paths, thus making path selection easier.

III. Wireless Network testbed

This section describes a wireless network testbed used for outdoor experiments. The testbed has been used in this work for experimental testing of influence of PCS. The experiment itself is described later in chapter IV.

Initially there were set criteria to the testbed which must be met:

- support for 802.11b/g/n network standard,
- autonomous supply of electrical power to allow outdoor measurements,
- possibility to reduce transmission distance to simulate network in limited area,
- software support for ad-hoc networking (integrated mesh routing protocols).

Based on requirements and WING/WORD toolkit description [8], hardware and software solutions described below were chosen.

A. Hardware

Six Cisco Linksys WRT160NL wireless routers were chosen equipped with Atheros AR9102 wireless network interface and two external antennas which is possible to remove or replace. Router has enough system memory (32 MB RAM and 8 MB flash) for firmware upgrade to more sophisticated platforms.

To make possible outdoor testing electric power supply for each device is required. For this purpose Uninterruptible Power Supplies (UPS) FSP Nano 360W were used. The main arguments for such choice were lightness (only 2.9 kg), Schuco sockets to plug router directly into the UPS and battery life (more than 4 hours). A wireless node is shown in Fig. 3.

Fig.3. A wireless node used in the testbed

B. Software

The original firmware of the routers was replaced by Open-Wrt [9]. It is a Linux distribution for embedded devices. It gives more control over device by allowing to modify physical layer settings. The biggest advantage over the main competitor's dd-WRT firmware [10] is a great variety of open-source software packages included which can be installed on the device to expand its functionality. Open-Wrt allows configuration through both Graphical and Command Line interface. For network throughput measurements an additional open source tool Iperf was installed.

The main disadvantage of such hardware and software setting was missing possibility to change Physical Carrier Sense threshold.

C. Routing

Open-Wrt makes it possible to install optimized link-state routing protocol (OLSR) [11]. OLSR is proactive ad-hoc routing protocol which uses both link quality and hop count metrics to calculate best path. Open-Wrt provides graphical configuration and monitoring interfaces for OLSR daemon.

IV. ANALYSES OF PHYSICAL CARRIER SENSE IMPACT

To evaluate PCS impact on network throughput in multi-path conditions the task was divided into three steps. First, results were obtained from network simulations and analytical calculations. Then wireless network testbed was used to perform "real life" measurements using the same network topology as for theoretical analyses. Finally results were compared and analysed.

We have chosen simple scenario which allows evaluating mutual impact of two routing paths. In this scenario six static nodes were placed into two rows. The network topology is shown in Fig. 4.

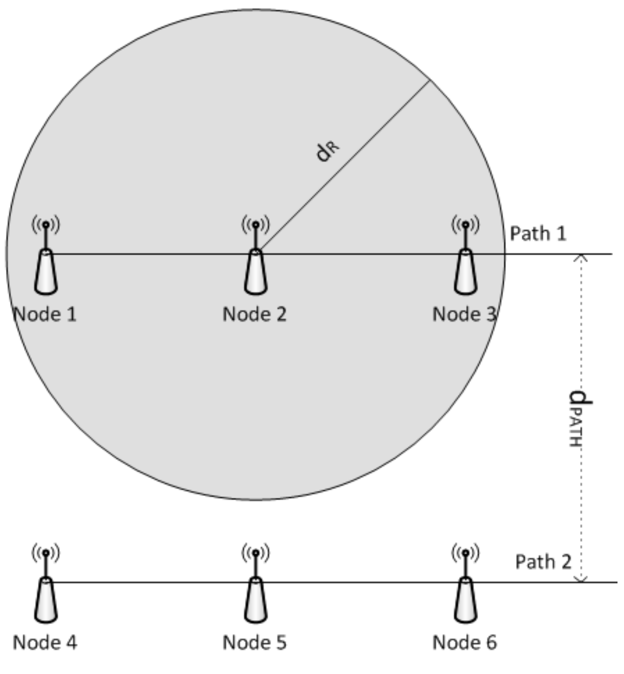

Fig.4. Network topology for two-path scenario with reception range for "Node2"

Nodes were placed so that they can send or receive data only from neighbours in the same path. It was achieved by taking distance between nodes of two paths greater than reception range d_R (d_{PATH}>d_R). We send network traffic over both paths and measure network throughput.

To choose distance between paths (d_{PATH}), it is important to determine a distance at which transmitter can sense ongoing data transmission from other transmitter. It can be calculated using formula (1):

$$d_c = \sqrt[4]{\frac{P_t}{P_{PCS}}} \quad (1)$$

here P_t - transmitter power, PPCS - PCS threshold. The distance dc defines the theoretical boundary beyond which two transmitters don't "hear" each other. It will be called PCS range. That concerns also the routing paths - placing nodes in paths in a distance greater than dc will help to avoid inter-path interference. However, one should keep in mind that in real life situations signal level from other transmitters sums up at a receiver's input, thus "safe" distance between paths might be even greater. In our analyses on purpose we will chose distance between paths smaller than PCS range to analyse the impact of inter-path interference on network throughput. In Fig. 5 the area where PCS of "Node 1" may sense ongoing transmission is coloured in grey.

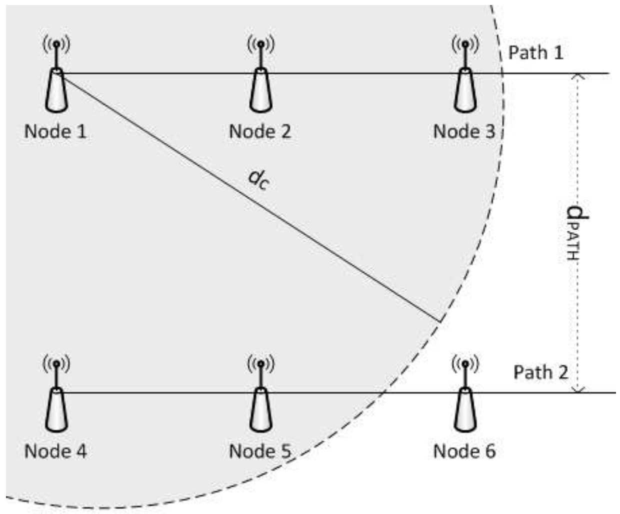

Fig.5. Network topology with the PCS range of "Node 1"

To observe network throughput changes in practice, data transmission over the first path starts later than over the second and also finishes earlier. In such way there will be a period when data are sent on both paths simultaneously. This period is our object of interest and we will compare traffic parameters in this time period with the same parameters in the period when there is no interference.

A. Simulation

For modelling Network Simulator 2 (NS-2) [12] is used. A network topology as showed in Fig. 5 was created. To simulate network traffic two FTP data transfer sessions were started (one for each path). Standard TCP transport protocol was used.

RTS/CTS handshake was switched off because as pointed out in works [4, 13] it is ineffective for wireless ad-hoc networks and traffic overhead it creates decreases network goodput.

Simulation parameters are summarized in next table (I).

TABLE I

NS2 SIMULATION PARAMETERS

Nodes	6
Simulation time	110s
First FTP session period	10s - 100s
Second FTP session period	40s - 70s
Distance between nodes	10m
Inter-path distance	14, 24m
Transmission range	15m
Carrier sense range	25m
Wireless standard	802.11b
RTS/CTS	Off
TCP packet size	1500 bytes

Two tests were performed each with different inter-path distance:

- d_{PATH}=14m. It is the distance at which maximum inter-path interference is possible. PCS areas of nodes overlap and therefore every node “hears” all the other nodes in the network.
- d_{PATH}=24m. Minimum inter-path interference is maintained. Every node hears only 3 neighbours (2 from own path and 1 from opposite).

B. *Experimental measurements*

The main motivation for experiments was necessity to test multi-path transport effectiveness in practice and validate results obtained from computer based simulation.

Measurements were performed in nature far from any man-made interference in this frequency band. The experiment area was a 100x100m plain field in which devices were placed as shown in Fig.5. Additionally two portable computers were wirelessly connected to nodes 1 and 4 to perform and visualize measurements. The computers could be the only interference sources.

Since real communication range for commodity 802.11b/g/n devices can be larger than 100 m we had to find solutions how to reduce this range to manage experiment in the smaller area. We performed such steps:

- power of wireless transmitters was decreased to 1mW which is the lowest possible level in configuration interface;
- only one antenna was used both for transmission and reception;
- devices were put on the ground (antenna height ~15-20cm);

In such a way it was possible to reduce stable communication range approximately to 5 – 10 m. Still, the ground was not ideally flat and orientation of devices may influence spatial pattern of transmission and reception range.

For throughput measurements Iperf network testing tool was used. Data transfer over TCP was performed similarly as in previously described NS2 simulation.

The experiment parameters are summarized in table II.

TABLE II

EXPERIMENT PARAMETERS

Frame size	1500 bytes
RTS/CTS	Off
Inter- path distance	7, 23m
Distance between nodes	5m
Transmitter power	1mW
Transmission range	5-10m
First Iperf TCP session period	10s - 100s
Second Iperf TCP session period	40s - 70s

Similar to simulation, the tests were performed at a different inter-path distances to test both - high and low inter-path interference conditions. The distances chosen in the simulation and the experiment slightly differed because transmission distances were also not the same. All devices were set to 802.11b standard to get comparable results with NS2 simulations.

C. *Results and discussion*

Figures (Fig.6, Fig.7) combine results both from simulation and experiment at high inter-path interference (nodes between two paths are close). A throughput of the data transmission over the first path is shown in Fig.6. Degradation of a throughput of the second path caused by interference from the first path one can observe in Fig.7.

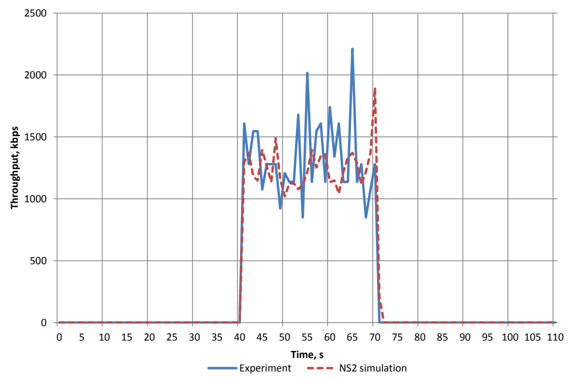

Fig.6. Throughput of the first path at high inter-path interference

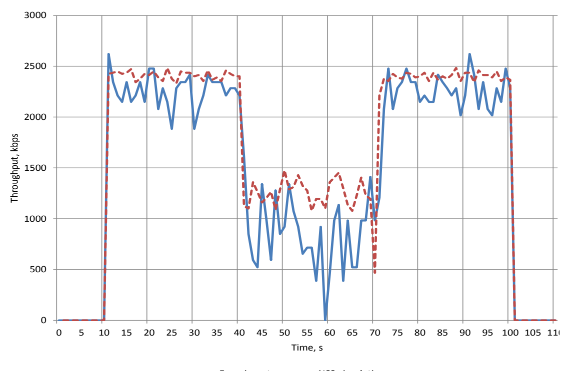

Fig.7. Throughput of the second path at high inter-path interference

NS2 simulation shows that throughput of the first path should reduce approximately by half during the interference period. Such distribution is logical because of symmetric topology. However, experimental measurements show that throughput drop in the first path is even greater, at the same time throughput of the second path is higher. It means that the second path has greater impact on the first than vice versa. That could be explained by imperfect experiment conditions, example, direction of antennas, uneven ground etc. and it must be clarified in future experiments. Still the most important conclusion is that total throughput of network has not changed when the second path is added. Sum of the throughput in both paths is about 2500 kbps.

Next figures (Fig. 8, Fig. 9) show throughput of the first and the second path in situation when there is a low inter-path interference. It was achieved by increasing distance between paths.

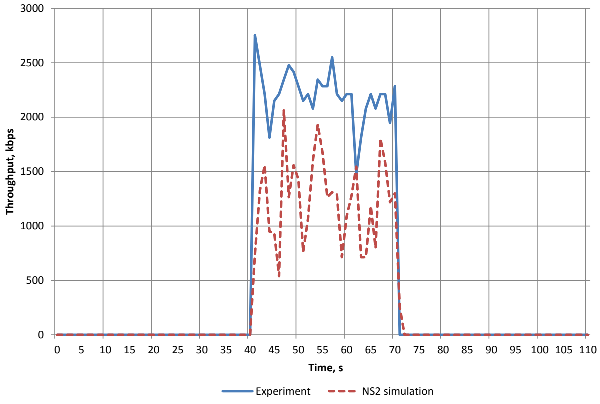

Fig. 8. Throughput of the first path at low inter-path interference

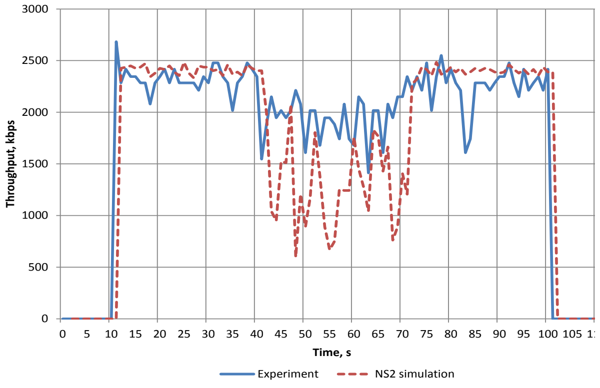

Fig.9. Throughput of the second path at low inter-path interference

From above figures one can see that experimentally measured throughput reduces less during interference period. Simulated threshold still drops at 50% level. The difference between simulated and experimental results couldn't be explained with confidence without more detailed experiments.

Conditions of the simulation were much idealized. In real life most likely each two nodes of different paths won't be positioned exactly at the same distance d_{PATH}. In Fig. 10 node 1 from the first path can "hear" node 4 from the second path while other nodes of the first path don't interfere with nodes from the second path because they are placed more distant. The described situation characterizes partial inter-path interference which may result in increased overall network throughput.

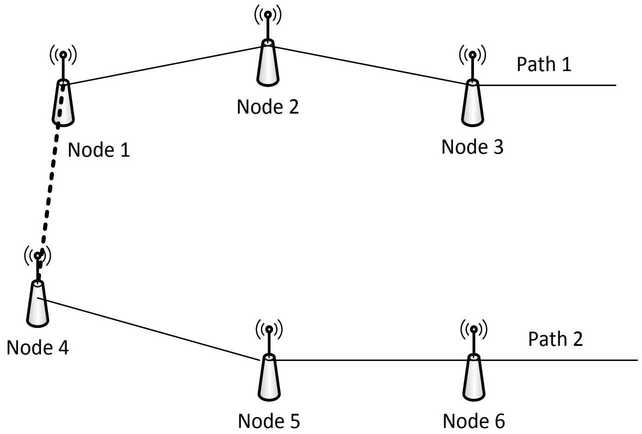

Fig. 10. Partly interfering paths

V. Conclusions

The Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) protocol may cause interference even if multiple paths for data transport are used. A wireless network testbed has been used for experimental investigation of inter-path interference in multi-path conditions. The experiment confirms results obtained from computer simulation program.

Both experimental and simulated results proved that there is a significant impact of physical carrier sense to multi-path transport effectiveness. When nodes of two paths mutually interfere due to physical career sense mechanism, multipath transport doesn't increase total network throughput. If interference is partial, some improvement of network throughput could be achieved. To increase network throughput, a distance between paths must be sufficient to keep inter-path interference negligible.

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Lauris Cikovskis received MSc in Electronics from Riga Technical University, Latvia in 2008. Currently he continues studies at doctoral level.
He works as a Research Assistant and Grid Computing Specialist at Riga Technical University, the Faculty of Electronics and Telecommunications. The fields of interest are wireless ad-hoc networks, grid and cloud computing technologies.
He is a member of IEEE

Ilmars Slaidiņš received Dipl.Ing in Radio engineering from Riga Polytechnical Institute, Latvia in 1971 and Doctoral Degree in engineering from the same institution in 1982.
He is a Professor and the Head of Department of Radio Systems at Riga Technical University.
He is a member of e-Infrastructure Reflection Group (e-IRG) and a member of IEEE.

Lauris Cikovskis, Ilmārs Slaidiņš. Fiziskā nesēja jušanas apgabala ietekme uz tīkla caurlaides spēju bezvadu ad-hoc tīklos
Tiek prognozēts, ka nākotnē strauji pieaugs informācijas apjoms mobilajos bezvadu tīklos. Tādi multimediju pielietojumi kā video straumēšana būs viens no visvairāk izmantotajiem. Taču video pārraide mobilos bezvadu ad-hoc tīklos (MANET) ir apgrūtināta, jo esošie pārraides un maršrutēšanas protokoli to neveic pietiekami labi. Tādēļ ir svarīga efektīvu video kodēšanas, pārraides un maršrutēšanas metožu izpēte.
IEEE802.11 standarta MAC līmenī kolīziju novēršanai tiek izmantots CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) protokols. Pie paaugstināta datu pārraides ātruma MANET tīklos šis protokols rada traucējumus starp mezgliem, kas ierobežo tīkla caurlaides spēju, kā arī var pasliktināt tīkla kvalitāti. Kā iespējamais risinājums tiek piedāvāta video sadalīšana apakšplūsmās un pārraidīšana pa vairākiem ceļiem vienlaicīgi, tādējādi palielinot kopējo pārraides ātrumu. Tomēr CSMA/CA ietekmē arī daudzceļu pārraidi, jo mezgli no dažādiem ceļiem arī var traucēt viens otram. Šī ietekme ir daudz pētīta ar modelēšanas programmu palīdzību, tādēļ šajā darbā tiek piedāvāti eksperimentāli novērtējumi fiziskai nesēja jušanas (Pysical Carrier Sense) ietekmei uz daudzceļu pārraides efektivitāti. Šim nolūkam tika izveidots bezvadu ad-hoc tīkls, kurā tika veikti mērījumi.
Tika pārbaudīts scenārijs ar diviem raidīšanas ceļiem un dažādiem attālumiem starp tiem. Ar nolūku fiziskā nesēja jušanas apgabals tika izvēlēts lielāks kā attālums starp ceļiem. Nepārtraukta datu plūsma tika pārraidīta otrajā ceļā un tika ieslēgta īslaicīga traucējoša datu plūsma pirmajā ceļā, tādējādi bija periods, kad abos ceļos bija vienlaicīga datu pārraide. Šajā periodā bija novērojama strauja caurlaides spējas samazināšanās otrajā ceļā. Ja attālums starp ceļiem tika paņemts lielāks, attiecīgi arī samazinājums bija mazāks. Eksperiments apstiprināja, ka fiziskā nesēja jušanas mehānisms stipri ietekmē daudzceļu maršrutēšanas efektivitāti. Kopējā tīkla caurlaides spēja var arī nepalielināties, ja mezgli no diviem ceļiem savstarpēji traucē viens otram. Lai panāktu uzlabojumu, ceļiem jābūt maksimāli nodalītiem.

Лаурис Циковскис, Илмарс Слайдыньш. Влияние зоны прослушивания несущей на пропускную способность беспроводных ad-hoc сетей.
Ожидается, что в будущем резко возрастет объем информации в мобильных беспроводных сетях. Мультимедийные приложения, такие как потоковое видео, будут одними из наиболее часто используемых. Тем не менее, возможности передачи видео в мобильных беспроводных ad-hoc сетях (MANET) ограничены, так как существующие протоколы передачи и протоколы маршрутизации недостаточно хорошо приспособлены к этой задаче. Поэтому, очень важно провести исследование эффективных методов кодирования видео, а также методов передачи и маршрутизации.
В стандарте IEEE802.11 MAC используется протокол предотвращения коллизий CSMA / CA (Carrier Sense Multiple Access с предупреждением коллизий столкновений). При высокой скорости передачи данных этот протокол начинает мешать эффективной передаче данных между узлами, что ограничивает пропускную способность сети, а также может ухудшить качество сети. В качестве возможного решения предлагается расщепление общего видеопотока на отдельные потоки и передача их по нескольким путям одновременно, тем самым увеличивая общую скорость передачи данных. Тем не менее, CSMA / CA действует также при передаче нескольким путям и узлы из разных путей тоже могут мешать друг другу. Этот эффект уже изучался многими исследователями при помощи программ моделирования, поэтому в данной работе предлагается экспериментальная оценка влияния Зоны Прослушивания Несущей (Pysical Sense Carrier) на эффективность передачи видеопотока многими путями. С этой целью она была создана экспериментальная ad-hoc сеть, в которой были проведены измерения.
Были проверены сценарии с двумя разными путями передачи и при разных расстояниях между ними. Для этой целью Зона Прослушивания Несущей была выбрана больше, чем расстояние между путями. Непрерывный поток данных передавался по второму пути и был кратковременно включен поток по первому, создающий помеху. В этот период обнаружено резкое снижение скорости потока по второму пути. Если расстояние между путями было больше, снижение скорости потока было меньше. Эксперимент подтвердил, что механизм Зоны Прослушивания Несущей сильно влияет на эффективность передачи данных с маршрутизации по нескольким путям. Общая пропускная способность сети может даже не увеличиться, если узлы двух путей создают помехи друг другу. Для того, чтобы добиться улучшений, пути должны быть хорошо разведены.