A Comparison of Collision Avoidance Methods Effectiveness in a Mobile Ad-hoc Network

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Abstract— Two selected collision avoidance methods, designed for application in wireless networks, namely: busy tone detection and control frames exchange, have been described. Their effectiveness in an ad-hoc network containing mobile stations has been compared. A criterion of effectiveness estimation for control frames exchange has been proposed.

I. INTRODUCTION

Wireless transmission is an increasingly more and more popular method of information exchange. In the era of cellular telephony this thesis does not need to be additionally acknowledged. Almost every portable computer is equipped with some means of wireless transmission. In this way wireless networks are formed, not excluding local area networks.

In the local area networks, the medium access protocols are one of the most important issues of network design [1]. If a protocol is not suitable for a specific application, the network may work not efficiently enough to provide the necessary parameters like, for example, throughput, link utilisation or QoS support.

In wireless networks several problems appear that are not known from wired networks, but play an essential role for the efficiency and stability of medium access control protocols. Their influence can be especially observed in ad-hoc networks (in this article, ad-hoc network is understood as a set of equivalent stations having similar capabilities and rights). These networks characterise with irregular and rapidly changing structure and they suffer from lack of supervisory control station that coordinates operation of remaining stations [2]. Therefore, practically only contention MAC protocols with distributed control can be used in wireless ad-hoc networks.

II. COLLISION AVOIDANCE AND DETECTION METHODS FOR WIRELESS NETWORKS

In wired networks, collision avoidance methods like carrier sensing are sufficient, as every station is able to detect transmission from any other station. If the collision detection mechanism is added, the protocol behaves efficiently and is stable enough for many applications. However, in wireless networks carrier sensing is not sufficient, because it is sensitive to the hidden and exposed terminal phenomena. In addition, capture effect disable collision detection in most cases (except some diffuse infrared systems operating under certain circumstances). Therefore, it is necessary to find new collision avoidance methods, which are more efficient than carrier sensing in the presence of hidden or exposed stations [3].

In this article, two collision avoidance methods for wireless networks are discussed:

- busy tone sensing (continuously during entire data transmission),
- control information exchange (before actual data transmission).

A. Busy Tone Sensing

The busy tone method replaces carrier sensing. The band is split into two channels [4]:

- message channel, used for data transfer and occupying most of the channel,
- busy-tone channel used for link status signalling, relatively narrow.

If a station has a frame ready to send, it must first check the link status before it starts transmitting. If a busy tone is heard, the link is assumed busy and therefore the transmission is restrained. Otherwise, the frame can be immediately transmitted.

The busy tone is usually a sine wave that can be generated in several ways:

- by every station that is able to detect transmission in message channel,
- by only the addressee of data frame,
- first by every station that can detect transmission, but when the destination address is already recognised – only by the addressee.

The first method [4] is the simplest one and very efficient in reducing number of hidden stations. However, this is achieved at a cost of unnecessarily increased number of exposed stations. One can say that the area occupied for some particular transmission is much greater than really needed. This observation is shown on fig. 1.

To avoid dramatically increased number of exposed nodes, the busy tone generation can be limited to only the addressee of the data frame [5]. This method protects the frame from the collision near the receiver – the only place where it really needs to be protected (there is no need to protect the frame near the transmitter or stations to which it is not addressed, because it doesn't have to be correctly received there). This method is simple as well, but it does not protect the frame until the destination address is recognised, so the frame is vulnerable at the beginning of the transmission. This approach is presented on fig. 2.

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The third method combines the advantages of the basic methods described above. There are two different busy tones [6]. The first one, called CD (Carrier Detected), is generated by all stations within the range of the transmitter as soon as the can detect a transmission on data channel. This continues until the stations recognise destination address. Then the intended receiver starts transmitting another busy tone, called FT (Feedback Tone), indicating no collision or other types of transmission errors. The remaining stations turn off their busy tone signals when they find they are not the addressees of the data frame.

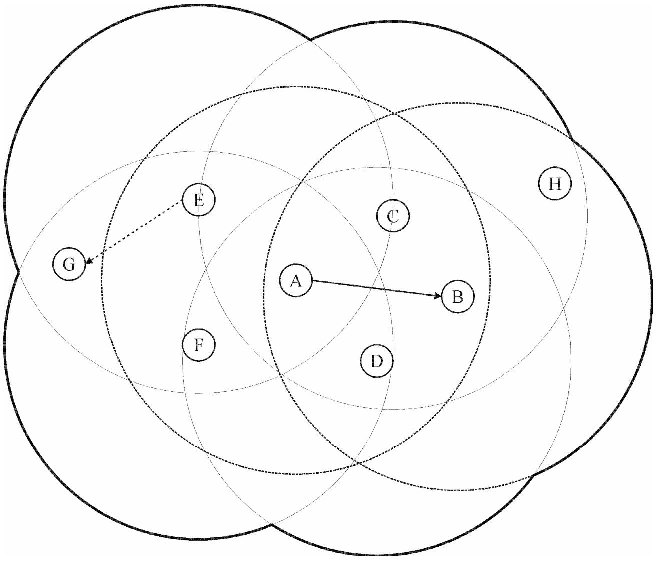

Fig. 1. Area occupied by a transmission using busy tone collision avoidance

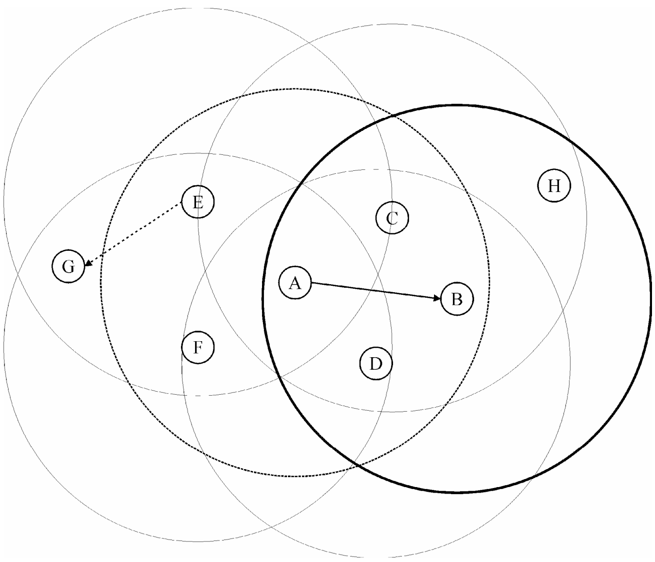

Fig. 2. Area occupied by a transmission using receiver-initiated busy tone collision avoidance

It is worth notice that the third method has some collision detection capabilities [6]. If the frame is divided into preamble (containing destination addresses) and body (containing data), it is possible to detect the collision early, i.e., before the body is transmitted. After the preamble is sent, the transmitter listens to the busy tone. Absence of the addressee's busy tone means collision or any other transmission error so there is no point to transmit frame body. From this point of view, this method behaves similarly to the control frame exchange. However, control frames support link status signalling that only precedes data transmission, while busy-tone based methods are capable of doing so continuously. Therefore, busy-tone seems to be more effective and stable when frequent transmission errors take place. This is because once control frame is lost, the station misses knowledge of link status, while in the busy-tone method it can be learned at any time.

Unfortunately, jamming the busy tone channel can easily block the network using busy tone based access method. Additionally, this method is not as easy to implement in practise as any single-channel method and thus, despite its interesting properties, it doesn't have any widely known practical implementation.

B. Control Frames Exchange

As carrier sensing is not an efficient method of collision avoidance in the presence of hidden or exposed stations, and busy tone is rarely implemented, one can use control information exchange preceding data transmission [7]. Such approach may be regarded as a form of a single-channel implementation of busy-tone sensing. However, busy-tone is replaced here by control frames, exchanged in the same channel as data. When a station has a frame to send, it must first send a control frame, called RTS (Request To Send), to the intended receiver. The frame should contain the information about data frame length. If the addressee receives the frame correctly and it there is no transmission nearby, it answers to the RTS sender with a CTS (Clear To Send) frame. This frame also should contain the data frame length. After proper reception of CTS in the sender, the link is assumed to be reserved for the transmission until the time specified in RTS or CTS elapses.

Besides the two stations actively exchanging control frames, other stations may also receive them. These stations may be divided into the following groups:

– stations hearing only RTS,
– stations hearing only CTS,
– stations hearing both RTS and CTS.

If a station can hear only the RTS frame, it is placed within the range of transmitter, but out of the range of the receiver and therefore it can be viewed as an exposed one. On the other hand, if a station can hear only the CTS frame, it is placed within the range of receiver, but out of the transmitter's range and therefore it can be viewed as a hidden one. If a station can hear both control frames, it is neither hidden nor exposed and could correctly detect the link status using only carrier sensing. These properties are shown on fig. 3.

It is important that the control frames could contain data frame length in order to inform neighbouring stations for how long the link will be reserved by the ongoing transmission.

It can be proved [8], that the CTS frame should be longer than RTS one, in order to properly protect data from collisions caused by hidden or exposed stations. However, an interesting fact is such that in IEEE 802.11 standard, CTS is shorter than RTS. By the way, it is worth say that control frames exchange, although theoretically much more efficient in networks containing hidden and exposed nodes, in this standard is only an option, while basic collision avoidance is based on theoretically ineffective carrier sensing.

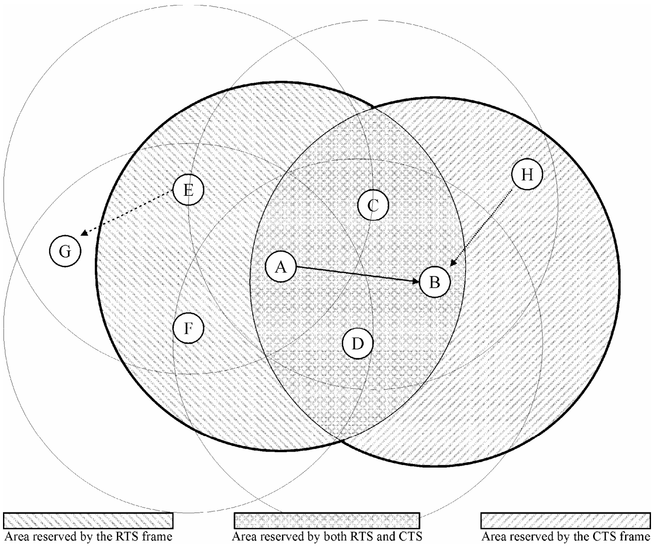

Fig. 3. Area occupied by a transmission using control frames exchange to avoid collisions

In some cases it is reasonable to use additional control frames. For example, after a proper RTS-CTS negotiation the sender may send additional frame, e.g., DS (Data Sending) [9]. This is especially useful when the receiver can't agree for the data amount suggested by the transmitter in RTS frame. In such a case, it sends a different value in CTS, but this information may be unavailable for some sender's neighbours if they are hidden from the receiver. Therefore, DS frame informs these stations about new link reservation time.

Another technique worth mention is acknowledgement generation on the MAC layer level [9]. Although higher layers can detect transmission errors as well, the MAC layer is capable of doing it faster, thus reducing the time necessary to detect collision or any other transmission error and request a retransmission.

Control frames exchange is a relatively simple and effective way to cope with both hidden and exposed stations. However, when applied alone, is not effective enough, because the control frames could collide [10]. The collisions are also likely to occur in mobile environments, when a station comes closer to those involved in transmission. In this case, it might be out of range during RTS-CTS handshake, but within a range during data transmission phase. Thus, this station has no knowledge about link reservation and thus it might interfere. Supporting control frames exchange with either carrier [10] or busy tone sensing [11] may partially eliminate these disadvantages.

III. Behaviour Analysis in a Mobile Ad-Hoc Network

The aforementioned collision avoidance methods, although they seem completely different, are in fact quite similar to each other. In both methods, a part of transmission band is sacrificed for sending of additional control information, defining link status. The difference, however, lies in the way the information is sent. Busy-tone based method keeps notifying of link status continuously during entire data frame transmission, while exchange of control frames, which allow determine link status, only precedes data transmission. This difference is presented on fig. 4. Although it does not make any danger in the case of networks that are either stationary or contain small number of stations of limited mobility, in case of complex ad-hoc network with large number of highly mobile stations may cause network efficiency deterioration.

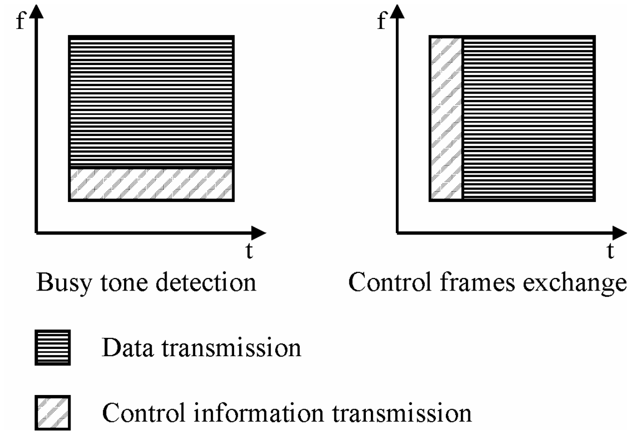

Fig. 4. A comparison of collision avoidance concepts

Let's consider an example of wireless ad-hoc network with mobile stations, as shown on fig. 5. Station S (sender) is transmitting data to station A (addressee). A mobile station M is travelling towards these stations, from the addressee's side. The mobile station is therefore beyond the sender's range. If the addressee protects the data frame with busy tone, the mobile station may acquire a proper information about link status regardless of the moment when it appears within the addressee's range. However, if sender and addressee use control frames exchange, the protection is not so effective. Namely, the mobile station should be within addressee's range when the CTS frame transmission starts. Any delay shall disable (entire) frame reception, which in turn causes effectiveness loss in the considered case.

For real ad-hoc networks, this case is too simplified. In wireless – especially radio – networks, Rayleigh or Rice fading occurs, which causes signal power drop with increasing distance to be not monotonic, but in large degree irregular. An example of relation between signal power and distance is shown on fig. 6. Local minima of signal power are placed at about half the wavelength $(\lambda/2)$ from each other [12], [13]. If such a minimum occurs below receiver's sensitivity, fading occurs. In such a case, station transmission ranges should be shown not as circles, but in more irregular way, like for example on fig. 7. Additionally, the faster the station is moving, the more often it suffers from fading. This effect is present not only in data networks, but also in “traditional” radio transmission. For example, when listening to the radio in a moving car, one can hear that the quality of radio reception is unstable.

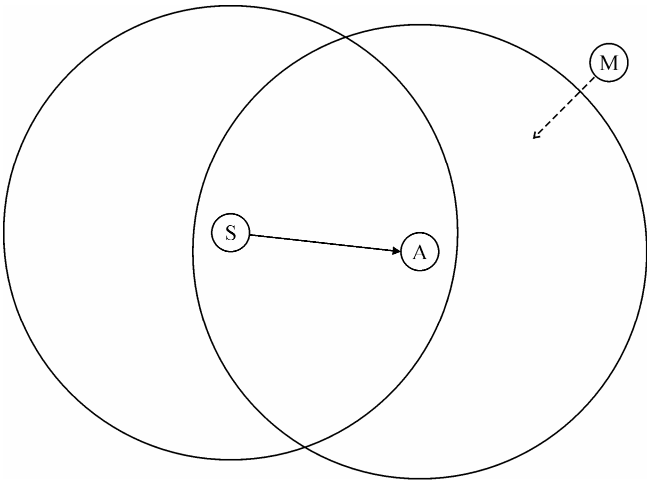

Fig. 5. An example of a mobile ad-hoc network

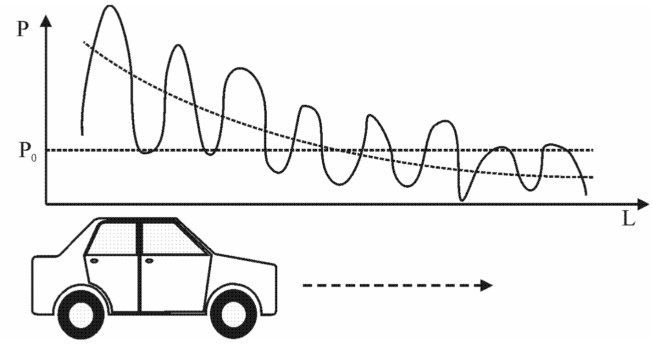

Fig. 6. A relation between mobile station’s velocity, distance and radio signal power level

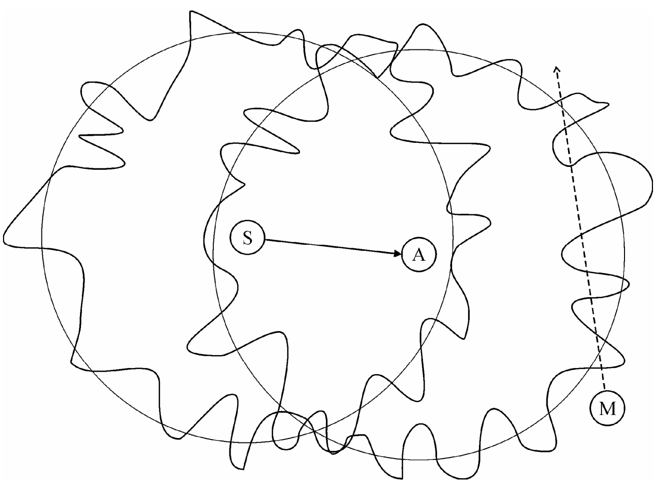

Fig. 7. An example of a mobile ad-hoc network with more realistic transmission ranges

Similarly to the previously described case, the sender (S) is transmitting to the addressee (A). Nearby the limit of addressee’s range a mobile station (M) is moving. Because of irregular line of the border, this station is continuously appearing and disappearing from the addressee’s range. As the placement changes, station’s ability to hear the busy tone signal varies as well, therefore, one can assume that this method provides sufficient effectiveness of collision avoidance. However, it is different in the case of control frames exchange. In order to make it effective, entire control frame (especially CTS) must fit between two consecutive fades. This is explained on fig. 8.

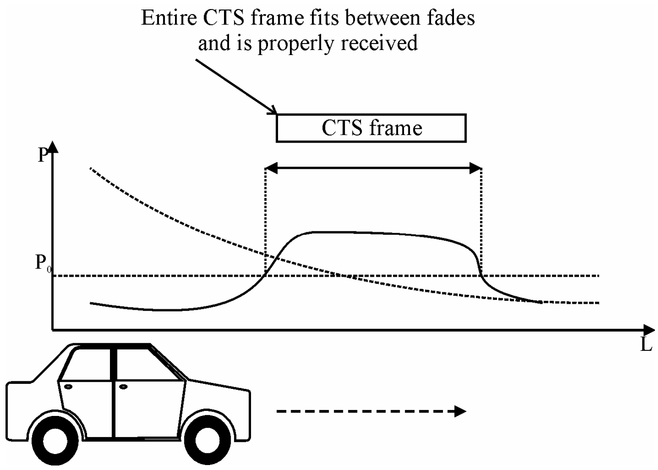

Fig. 8. Explanation of conditions of proper frame reception by a mobile station

Let’s assume, that:

- transmission range of busy tone channel and data channel are equivalent,
- carrier detection time and busy-tone detection time is negligible,
- radio frequency equals to f , and wavelength – λ ,
- the mobile station is moving with velocity of v .

Time, necessary for mobile station to pass the distance of $\lambda/2$, equals to:

$$t_{fad} = \frac{\lambda}{2v}. \tag{1}$$

In order to enable proper reception of CTS frame, its transmission time (including physical layer elements, like for example preamble and receive-to-transmit switch time) must be not longer than the time that elapses between two consecutive fades. If the distance between two fades equals to $\lambda/2$, then, as shown on fig. 3, received signal level exceeds receiver sensitivity in average in twice smaller distance. Thus,

$$t_{CTS} = \frac{t_{fad}}{2}. \tag{2}$$

In practice, this time may appear even shorter.

Bearing in mind these considerations, in order to preserve effectiveness of control frames exchange based collision avoidance, mobile station (M) velocity is limited and may not exceed

$$v \le \frac{\lambda}{4 \cdot t_{CTS}} = \frac{c}{4f \cdot t_{CTS}}. \quad (3)$$

For example, in IEEE 802.11 standard (in its most basic variant), with the transmission rate of 1 Mbps and direct sequence spread spectrum, transmission time of CTS frame is about 320 µs, where 192 µs are sacrificed for physical layer preamble and header. At the radio frequency of 2.4 GHz we get

$$v \le \frac{c}{4f \cdot t_{CTS}} = \frac{3 \cdot 10^8 [\mathrm{m/s}]}{4 \cdot 2.4 \cdot 10^9 [\mathrm{Hz}] \cdot 320 \cdot 10^{-6} [\mathrm{s}]} = = 97{,}7 [\mathrm{m/s}]. \quad (4)$$

It is worth say that other versions of the standard (IEEE 802.11b or 802.11g) have shorter preambles and higher transmission rates, which allows greater stations mobility. However, it must be noticed that short preamble service is optional, while control frames may be transmitted at lower rates than the maximum for a given standard. Under such circumstances, stations mobility may still be limited. Nevertheless, in many applications the speed limit described above may be negligible.

The criterion presented is only an approximation. On fig. 6 one can see that, with increasing signal power level, the distance between fades is larger, which in turn allows proper network operation at higher mobile stations velocities. Similarly, at lower signal power level, allowable velocity is much smaller.

It is necessary to say that fulfillment of the presented criterion does not guarantee that CTS protection will always be effective. It might happen that, even if mobile station traveled with sufficiently low velocity, CTS frame would not be entirely sent between fades, thus would not be properly received. This case is shown on fig. 9. In order to always send CTS effectively, i.e., between fades, crossing range borders by mobile stations should be synchronized with CTS transmissions, similarly to traffic lights. Unfortunately, that does not seem technically possible, but even if it was, it would require a very complex control, a cost of which might be higher than advantages resulting from increased effectiveness of collision avoidance.

It is also worth notice that – within the range of accepted assumptions – velocity limitation does not affect busy tone-based collision avoidance method. In fact, continuous data frame protection found in this method is entirely immune to stations mobility as long as mobile stations hear busy tone not later than they fall within receiver's range.

IV. Conclusions

The presented considerations show that current technologies of lower wireless network levels support stations mobility in sufficient degree. However, a tendency to move radio communication towards higher and higher frequencies may be observed; as a result, distance between places where fades occur decreases. This phenomenon limits stations mobility in some degree, which may be unacceptable in certain mobile applications. On the other hand, this effect is neutralised by large growth of transmission rate.

Presented effectiveness estimation method, applicable for collision avoidance method based on control frames exchange, may be used to analyse any type of mobile, wireless networks. However, it is especially important for radio networks, because infrared-based transmission systems do not suffer from fading as the size of infrared detectors is much larger than wavelength. Another fact is such that limited transmission range of diffused infrared networks does not allow stations to be highly mobile. However, in some cases, presented considerations may apply to infrared networks, too.

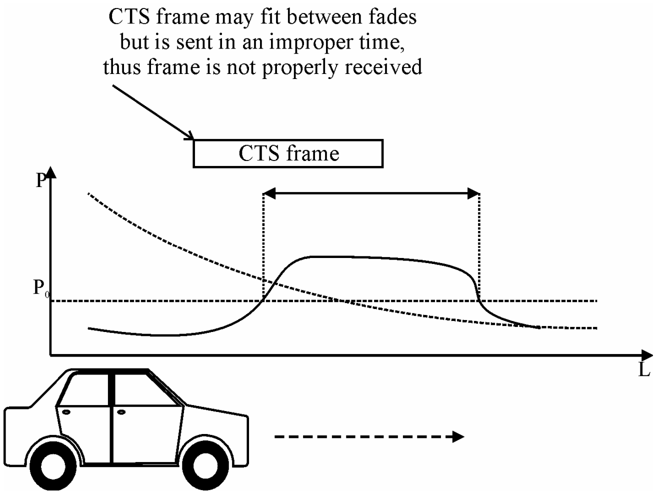

Fig. 9. Explanation why presented criterion fulfillment is not sufficient to ensure proper CTS reception

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