International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 3 Issue 12, December-2014

Survey on Multi- Channel Access Methods for Wireless LANs

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Abstract— **The last decade has seen great progress in the field of wireless LANs. Their deployment is manifested in several areas of applications. However, these applications face many obstacles due to the complexity of managing the medium access. This shortcoming usually leads to some problems such as numerous collisions, throughput degradation and increased delays. To overcome these challenges, research works have focused on new multi-channel access methods that reduce contention as well as collision probability. Several transmissions can occur simultaneously in the same transmission area, thus considerably improving throughput and reducing delays to access the medium. However, the idea of using multiple channels arouses various problems such as the multi-channel hidden terminal, deafness and the logical partition. We present in this paper main multi-channel access methods generally discussed in the work of the scientific community. They are classified into two main categories: (1) the single rendezvous approach such as the split-phase, the dedicated channel and the common hopping; (2) the parallel rendezvous such as SSCH (Slotted Seeded Channel Hopping) and McMAC (Parallel Rendezvous Multi-Channel MAC Protocol). We can then deduce that for a multi-hop topology that we envision to achieve with a very reduced radio cost, some of these methods are not suitable for the desired single interface prototyping.**

Keywords—Wireless LANs; Medium Access Control; Multi-channel

I. INTRODUCTION

By definition, mobile ad hoc networks consist of mobile nodes that are connected via wireless links without using an existing network infrastructure or any centralized administration. The nodes are free to move randomly and organize themselves arbitrarily; thus, the topology of wireless network may change rapidly and unpredictably. Mobile Ad hoc networks do not require any network infrastructure to be present, such as fixed node or base station for their operation. Usually communications between nodes are multiple hops (i.e., a node need to pass through intermediate nodes to reach a destination), we call these types of topologies "ad hoc multi-hop wireless networks". Each node is able to communicate directly to one hop with another neighbor node that is in its transmission area. To communicate beyond one hop with nodes that are outside its transmission area, the node needs to use intermediate nodes to relay messages at each hop. Thus, design a MAC access method that must take into account both the multi-hop context and of the dynamic and unpredictable nature of the network topology is essential and complex. One of the major roles of an efficient access method is to manage access to the medium, and therefore, to solve the inherent problem of wireless hidden node where a transmitter node may not hear the transmission from another node that is not in its radio range.

The multi-channel access methods allow different nodes to transmit simultaneously in the same coverage area on distinct frequency channels generally. This parallelism increases the throughput and can potentially reduce the transmission delay and contention. However, the use of multiple channels does not go without problems. The majority of wireless communication interface is operating in half-duplex: they are either in transmit mode or receive mode. The radio interface is able to dynamically switch to channels, but it cannot transmit and listen to a radio channel at the same time. In addition, when a node is listening to a particular channel, it cannot hear the communication that takes place on another channel. We also face other challenges than those of a classical single-channel medium access protocol, namely: the multi-channel hidden terminal, bottlenecks problem, and other problems such as the logical partition and deafness. In this paper we first introduce the multi-channel problems, then the main existing multi-channel access methods that are often proposed in a single-hop context and the advantages and disadvantage each of them. We then identify which of these single-hop multi-channel access methods are suitable for multi-hop cases and then we discuss the main multi-hop multi-channel access methods proposed in the literature with their different constraints.

II. INTERESTS OF THE MULTI-CHANNEL APPROACH COMPARED TO SINGLE CHANNEL

In a single channel and single-hop transmission, the data transmission channel is a shared resource among multiple nodes in the same area of communication range. The nodes will then compete for access to the resource; therefore, collisions may sometimes occur, thus affecting throughput and delay. When multiple channels are used, concurrent transmissions in the same coverage area may run in parallel on different available channels, thereby improving performance in terms of throughput and delay. As shown in Fig. 1, the three transmissions occur simultaneously on the three channels and into one time slot, which triples the overall throughput compared to single-channel system and also reduces the delay of two time slots.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
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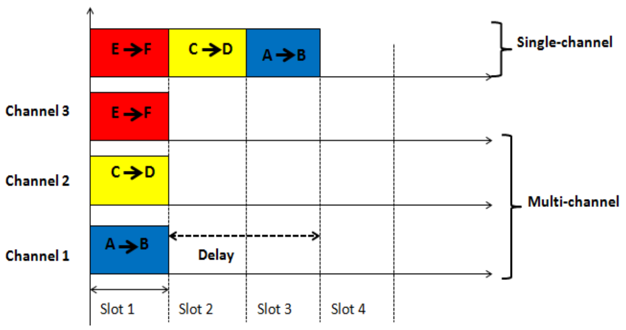

Fig. 1. interest of a multi-channel system compared to a single channel system

III. MULTI-CHANNEL ISSUES

Multi-channel access methods face several major challenges, some of which are practically the same as their single-channel counterparts. We can cite for example the hidden terminal problem (single-channel case), the bottleneck on the dedicated control channel (multi-channel case), broadcast problem (single and multi-channel case), deafness (multi-channel case) and the logical partition (multi-channel case).

The main difficulty for multi-channel access is the choice of channel to use and the sharing of available channels by the nodes in a distributed context. In the multi-channel context, when a node needs to transmits data, it must necessarily know the channel on which its receiver is ready to receive the sent data [7]. Therefore, the multi-channel MAC protocols require a specific mechanism that will be responsible for the channels allocation, i.e. to decide which channel will be used by which nodes and at what time. The main role of the mechanism is to implement methods for the choice of a channel by the nodes. Thus, the transmitter and receiver must finally return on the same channel at the same time for their exchanges data. This is what we call the establishment of a rendezvous by the nodes.

A. *multi-channel hidden terminal problematic*

The multi-channel hidden terminal problem [1]; [3]; [7]; [9]; occurs very often when the nodes are equipped with a single radio interface, resulting in a lack of information on the state of some channels. This causes thereafter collisions at the receivers. As can be seen in Fig. 2, after exchanging RTS and CTS control frames on channel 1 (control channel by default), nodes K and L decide to use channel 2; at the same time F and G decide to use channel 3; K and L are not aware of the channel choices of F and G, and decide to use channel 2, then causing a collision at the receiver G.

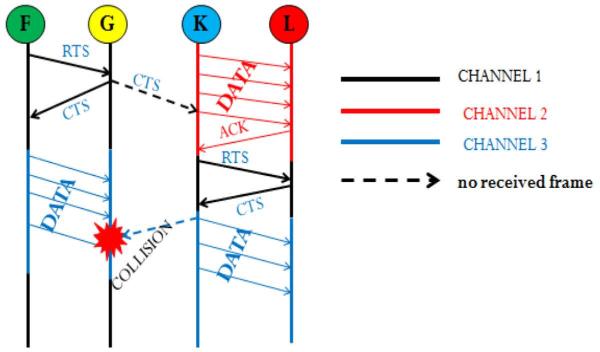

Fig. 2. multi-channel hidden terminal problems

B. *deafness problem*

The deafness problem occurs due to the lack of information on the channel used by the destination node. Thus, the control frame on the control channel misses his destination, busy on another channel. This problem can be seen in Fig. 3. After exchanging control frames on channel 1, G and K switch on channel 2 to transmit data. Not having any information on the fact that the node G is active on channel 2, node F sends several controls frames RTS on channel 1(control channel by default) to node G, but receives any response from node G; therefore F incorrectly concludes that the link between F and G is ruptured and thereafter abandons the data transmission. In addition these control frames overload the control channel unnecessarily.

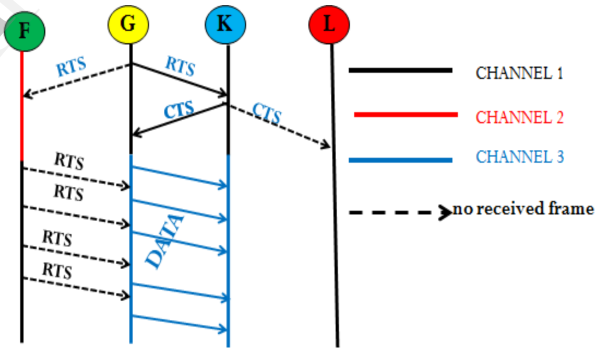

Fig. 3. multi-channel deafness problem

C. *logical partition and broadcast problematic*

The problem of logical partition is another case that occurs when a part of the network is isolated from other nodes by a lack of information on the channels utilization [7], [10]. Broadcasting is an important activity in the Ad-hoc networks [3], [10], [15], especially when it broadcast a frame to coordinate all nodes in the same coverage area. This broadcasting activity (without ACK) is quite simple in a single channel access method since all nodes listen to the same channel. However, in a multi-channel context, this phenomenon is often complex by the fact that nodes switch to different channels to transmit or receive data; therefore, they can easily miss a broadcast frame (which usually is not acknowledged so non-secure and thus definitively lost for them). In [15], to solve this problem, the authors use a technique for broadcasting a beacon on the control channel. This beacon contains the time that the broadcast frame will be transmitted. All nodes that have received this beacon should wait on this channel to receive a broadcast frame, even if the node has already negotiated another channel (rendezvous) to transmit data. To find solutions to the various multi-channel problems that we have evoked, most of the researchers have proposed four main approaches, but several have addressed the problem only in a single hop context.

IV. COMPARATIVE CRITICAL ANALYSIS OF THE EXISTING SINGLE-HOP MULTI-CHANNEL ACCESS METHODS

A. Introduction

An ad hoc wireless network is composed of a group of node. Each node is equipped with a wireless interface card and can be deployed quickly, without any established infrastructure or centralized administration. The radio range of each node is limited either by the power limitations, or by the presence of obstacles, a mobile may not be able to communicate directly with other destinations nodes except in an ideal single-hop topology qualified clique. In the general case, a multi-hop topology is needed, where the sent frames from a source node must be relayed through one or more intermediate nodes before reaching their final destination. We recall that the first issue of these types of networks is the medium access method management. This latter has been the target of several research, but most often in a single-channel context. Recently, studies have addressed the multi-channel case and some results could already serve as a basis to extend the capacity and performance of the network and its medium access method. It is also essential to think about multi-channel and multi-hop case, since the existing studies are often limited to a single-hop framework [12]. The multi-channel MAC protocols for ad hoc wireless networks that have been proposed allow different nodes to transmit in parallel on distinct channels without collision, thereby increasing throughput and potentially reduce transmission delays. However, most of the proposed protocols are single rendezvous protocols that are subject to congestion control channel. In general, the different protocols are distinguished by the manner in which the network nodes establish rendezvous or in other words, how the nodes negotiate the channels to use for data transmission.

B. DCA

The first multi-channel MAC protocol that was presented in [1] and [2] is called DCA (Dynamic Channel Assignment); it uses two interfaces: one interface for control frames exchanges and the other for data transfers. In this protocol, each node maintains a list of free channels (Free Channel List FCL) to register free data channels. With DCA, when source node has data to transmit, it transmits an RTS frame (Request To Send) including the list of available channels (FCL) that are not used by its one hop neighbors. After receiving the RTS, the destination node compares the received FCL with its own FCL and selects a common free channel. Then, the destination node indicates to the source node and its neighbors, of the selected data channel by sending a CTS (Clear To Send). By receiving the CTS, each node also informs its neighbors of the selected channel by sending an RES (Reservation)frame. We note that compared to the IEEE 802.11 DCF standard, DCA protocol requires an additional control frame RES to reserve the selected channel.

C. Single RDV & parallel RDV

In [1], [3] and [4], the authors classify the multi-channel MAC protocols into two categories: the single rendezvous (i.e. the dedicated control channel), the common hopping, Split Phase, and parallel rendezvous protocols for example SSCH (Slotted Seeded Channel Hopping) [5] and McMAC (Parallel Rendezvous Multi-Channel MAC Protocol) [6].

The single-rendezvous MAC protocols have a common control channel also called rendezvous channel. Nodes can exchange control frames and negotiate channels for data transmission on this channel. This control channel, however, can become a bottleneck as the data traffic increases and requests for rendezvous too. Parallel rendezvous MAC protocols, on the other hand, do not need a common control channel. The main idea of these protocols is that nodes hoping between different channels according to their own sequences and control information are exchanged on different channels. Several rendezvous can then establish simultaneously; nodes stop their hopping when they conclude agreements and begin to transmit data and then resume their hopping sequences at the end of the transmission.

In [3], Crichigno, J., and *al*. compare the single and parallel rendezvous protocols in terms of channels number and throughput; according to their study and considering that all nodes are equipped with a single radio interface, they deduce that the parallel rendezvous protocols such as McMAC and SSCH are more efficient than single rendezvous protocols because they eliminate the control channel bottleneck.

In [7] El Fatni and *al* propose two multi-channel MAC solutions in order to overcome the control channel bottleneck problem. One protocol is called PSP-MAC (Parallel Split Phase multi-channel MAC), which exploits the split phase by applying parallelism during the control phase. The main objective is to exploit all channels during this phase. The second proposed protocol is PCD-MAC (Parallel Control and Data transfer multi-channel MAC), it exploits the concept of multiple rendezvous and dedicated control channel. This protocol excludes the concept of two phases per cycle. Unfortunately, these propositions do not take into account natively the multi-hop topologies, even if the author thinks that its proposals should still be efficient in a more realistic topology.

D. The dedicated channel

The dedicated control channel protocol is based on a unique rendezvous [1], [3], [4], [12]. Each node has a control interface and a data interface. The control interface is permanently fixed on a common channel (called the control channel) for the control frames exchange. The data interface can be switched between the remaining channels (called data channels) for the data transmission. The main idea of the protocol is to isolate the control frames of those data by assigning a fixed channel for exchanging RTS and CTS control frames and thus avoid interference between the control frames and data packets. Several studies consider the protocol multi-interface, while El Fatni and *al*. [12] consider it among the single-interface multi-channel protocols.

The principle of the protocol operation is the following: when a pair of nodes A and B wants to exchange data, the sender A sends an RTS frame containing a list of free channels in its coverage area on the control channel. The receiver B selects a common free channel among the channels from the list sent from A by responding with a CTS frame that includes the selected channel for data transfer. Then, A and B switch their interfaces on the selected channel and begin transmitting data. The RTS and CTS frames also include the NAV (Network Allocation Vector) to inform the A and B neighbors of the time during which the channel will be busy. In [12], the authors use a third additional control frame RES (Reservation) at both RTS and CTS frames to confirm the reservation of the channel. Fig. 4 explains the dedicated control channel principle. The advantage of this protocol is that it simplifies the broadcast frame, since there is a fixed radio interface permanently on the control channel, thus the broadcast in one hop will be performed on this channel. The disadvantage of this protocol is that it does not provide a solution to the major multi-channel hidden terminal and deafness problem. As the control channel is unique, if several nodes try to conclude agreements to transmit data, the control channel becomes a bottleneck. Thus, during the data transmission period, the nodes have any information about the rendezvous established on the control channel, and thus ignore the information on the reserved data channels during this period. This lack of information leads to the following problems: 1) The multi-channel deafness problem where a node seeks to establish a rendezvous with another node located on another channel transmitting or receiving data. 2) Multi-channel hidden node problem occurs where two nodes establish a rendezvous and switch on a channel that is already occupied by another peer node. We also note that during the data transfer, the control channel is not used. This proves that the dedicated control channel approach also wastes bandwidth. 3) In the multi-hop case, we should find a solution to diffuse more than one hop RTS, CTS frames (and eventually RES) to nodes that can hinder the exchanges DATA-ACK.

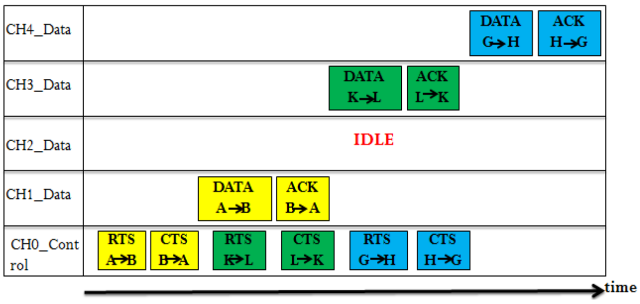

Fig. 4. Principle of the dedicated control channel

E. The split-phase protocol

Many studies have addressed this approach [1], [3], [4], [12]. The nodes use a single interface and the time is divided into an alternating sequence of control and data exchange phases. During the control phase, all nodes switch their interfaces on the control channel and try to conclude agreements for the channels that will be used during the next data exchange phase: all nodes periodically take rendezvous on a common channel in the control phase.

The operating principle of this approach is illustrated by Fig. 5.

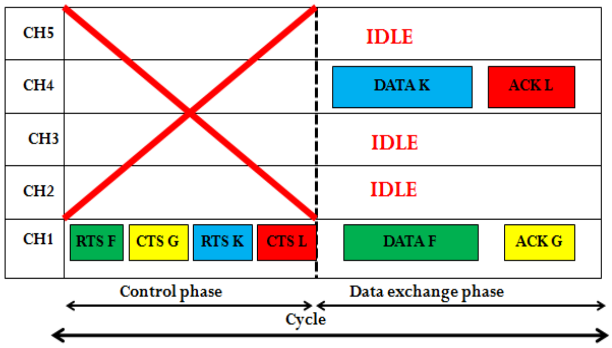

Fig. 5. operating principle of split-phase
Fig. 6.

At the beginning of each cycle, a control phase is opened, all nodes switch on a common channel, the control channel or rendezvous channel. We note here that the nodes F/G and K/L are trying to conclude rendezvous by exchanging RTC/CTS control frames during the control phase on CH1 (channel control by default). Nodes F and K include a list of favorite channels or PCL (Preferable Channel List) when they send RTS frames. Each nodes G and L selects a channel from the list of their transmitter by returning a CTS. According to Fig. 5, for example, from the RTS and CTS frames, the neighbor of G, is the node K knows that CH1 will be busy for the next phase of data exchange. Therefore, when the node K sends an RTS to node L, it does not include the CH1 in his list of favorite channels, but rather, it selects another available channel, as seen in the Fig. 5, the CH4 channel. In the case where the transmitter and receiver do not find a common channel, the negotiation of a channel will be deferred to next cycle [12]. When a node is idle during the control phase, it will remain idle for the data phase [12].

The advantage of this approach, since the nodes exchange lists of channels, this will enable to mitigate the multi-channel hidden terminal and deafness problem. By comparison of the dedicated control channel protocol, this protocol exploits all channels including the control channel during the data phase. But its main disadvantage is that synchronization between nodes is required. Moreover, the protocol does not use all available channels during the control phase, a single control channel is used during this phase, so in case of high traffic load, it becomes a bottleneck. We also note that during this phase, significant bandwidth is wasted. That to say L_{cycle} : is the cycle length; L_{cp} : the control phase length; N: the number of available channels; P_{rc} : the percentage of bandwidth wasted during each cycle, is then:

$$Prc = \frac{\frac{N-1}{N} * Lcp}{Lcycle} * 100$$

It is also complex to estimate the appropriate length of the control phase, on the other side for the data phase depends on the number of negotiations established in the previous phase. A small length is the source of bottleneck obviously a larger length is bandwidth wastage [12]. Thus, the control phase length remains principally the most difficult parameter of this approach. The split phase is well adapted to single-hop case, it would modify it for the multi-hop case in order to make known to the neighbors to more than one hop the PCL lists.

F. The common hopping protocol

Several studies have addressed this approach: [1], [3], [4], [12]. The nodes are equipped with one interface and time is divided into time slots or slots. Each slot is at least equal to the time required to control frame exchange. All nodes follow a common hopping sequence through all channels and synchronously. The main goal of this approach is to exploit all data channels. Thus, nodes that want to exchange data stop to hop from channel to channel and remain on the same channel to transmit after control frames exchange RTS/CTS; while the other nodes continue to follow the hopping sequence. After finishing their transmission, the nodes resynchronize with others and continue to follow the common hopping sequence. Here we see in Fig. 6. , the nodes A, B, C, D... Z, at time t1 switch on channel 1. But at t2, we see that A and B after exchanging controls frames successfully, remain on channel 2 to exchange data and acknowledgment. Other inactive nodes continue to follow the common hopping sequence. According to the Fig. 6 , at time t3, such as nodes A and B are active on channel 2, so they are absent on channel 3. At time t4, F and G exchange data on channel 1, they are also absent at the time t5 when the nodes switch on channel 2. At t6, we note that nodes A and B have finished their transmission and resynchronize with the other nodes by following the common hopping.

By comparison with previous approaches, the common hopping protocol allows to exploit all data channels hence his advantage, but the major disadvantage is that it requires strict synchronization mechanism and also suffers from a high switching frequency between channels, multi-channel hidden node and deafness problems (in multi-hop context). On a multi-hop topology, it would reach to do know the nodes in more than one hop, that a couple of nodes decides to meet on a private channel different from common hopping for exchanging.

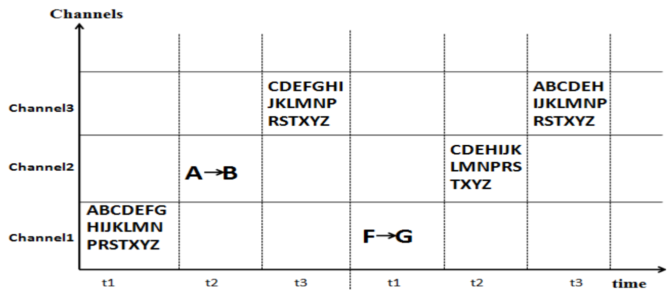

Fig. 7. Principle of operation of the common hopping protocol

G. Independent hopping Protocol

This multi-channel MAC protocol allows multiple rendezvous simultaneously on different channels. The nodes are equipped with a single interface and switch on the channels according to their own sequences. Time is composed in sequences cycle and each cycle is divided into several time slots. The nodes then iterate on their own hopping sequences and overlap at least for a time slot per cycle, allowing them to exchange and learn their sequences to each other. In [5], to avoid the partition of the network, it is required that the nodes hop on a predetermined channel after iterated through all channels of their own sequences. This is not the case proposed in [6] for which the nodes overlap during their hopping sequences where each node announces its hopping sequence.

For SSCH protocol (Slotted Seeded Channel Hopping) [1], [3], [4], [5], the nodes in the network switch on a predetermined channel after having iterated on their different hopping sequences, thus allowing them to exchange their sequences. Thus, when a node wants to transmit, it waits until its sequence corresponds to that of its receiver, then the transfer will be realized on successive hops to the receiver sequence. As seen in Fig. 7, the nodes F and G each follow their own sequence, indicated on the blue dotted circle. On the green dotted circle, it is seen that both nodes F and G hop on the channel CH4. At time t6, node G starts to follow the F sequence to forward data. The data transfer will then be performed on successive hopping sequence receiver F. To achieve a multi-hop topology must ensure that once all nodes by switching on the predetermined channel (e.g. channel CH3 Fig. 7), find a way to diffuse their sequences beyond at one hop, especially if there are pairs of nodes that wish to exchange data.

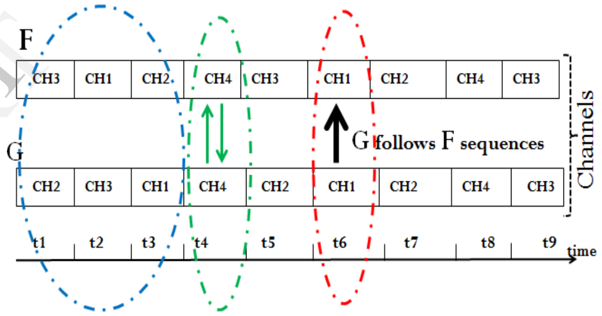

Fig. 8. Principle of operation of the independent hopping protocol (e.g. SSCH)

The McMAC protocol (Parallel Rendezvous Multi-Channel MAC Protocol) [1], [3], [4], [6], provides some corrections on the operation principle of SSCH in order to eliminate the waiting delay caused by the transmitter node. For McMAC then the nodes overlap at least for a time slot per cycle to exchange their hopping sequences, the node already knows the receiver's sequences, it hops on the channel of receiver's hopping sequence, and data transfer is entirely realized on this channel.

Parallel rendezvous protocols have the advantage to eliminate the potential bottleneck problem of previous approaches with a single radio interface by allowing multiple rendezvous on different available channels. But the main disadvantage of these protocols is the switching delay for the channel hopping. In addition, each node requires synchronization mechanisms to follow the other's hopping sequence. Most protocols studied and presented do not take into account the multi-hop aspects and operate correctly for the most part only in a very theoretical topology where each node is within range of any other node. As we evoked to each protocol presented, modifications are necessary to adapt them to the multi-hop.

It must indeed be able to propagate more than one hop the exchanged information in the clique so that more distant neighbors do not disrupt the exchanges by not respecting rendezvous taken locally between nodes in range.

V. INTEREST STUDIED APPROACHES IN THE MULTI-HOP CONTEXT

One of the preceding studied approaches complexities for ad hoc wireless multi-hop networks is the necessity to take account of the need for synchronization between network nodes, which can be solved by the SISP protocol [11] internally developed in IRIT-IRT laboratory. The ad hoc multi-hop multi-channel networks topologies also suffer from multi-channel hidden and exposed terminal problems, and finally, the resynchronization (that is to say, be able to give them temporal information of the taken rendezvous) of two nodes in activity on a channel at a given moment to the rest of network remains difficult with the constant change of network topology.

Parallel rendezvous protocols eliminate the bottleneck problem by exploiting multiple channels at once, but this is not finally the major problem of a multi-hop ad hoc network. in fact, in these types of networks, the transmission and reception data is not only affected by the nodes in one hop, but generally beyond to one hop. This lets understand that the hidden and exposed nodes problems are more frequent in the multi-hop networks. Note also that the independent hopping protocols also require for each network node, synchronization mechanisms in order to follow the hopping sequences of other nodes. In addition to this activity, in multi-hop ad hoc context, mobility dynamically modifies the network configuration, in order to adapt to the mobility, network nodes must constantly exchange topology information. Design a multi-channel MAC protocol which will take into account all these parameters and all these constraints appears complex.

Based on these observations, we can deduce that the parallel rendezvous protocols allow to exploit efficiently all the network channels, but they also impose parameters and procedures that are difficult to exploit in a multi-hop context. On the other side, the other two approaches dedicated control channel and split-phase give the possibility to exploit them in a multi-hop context with minor modifications. These latter use in common a single channel called the control channel for all nodes in the network at a given time, where each inactive node listens this channel. Given that the broadcast activity is very important in ad hoc multi-hop networks, to exchange information on the dynamic network topology, the synchronization is simpler compared to the common hop, these approaches simplify the multi-hop context.

VI. MULTI-CHANNEL MULTI-HOP ACCESS METHOD

Some research works have also mentioned in particular, the multi-channel multi-hop access. In this part we will describe their principle.

A. CSMA Multi-channel

Nasipuri and *al* [13] have implemented a multi-channel CSMA(Carrier Sense Multiple Access) MAC protocol for multi-hop wireless networks. The main aim of their study is to reduce collisions that occur during transmissions in wireless networks and also reduce the effect of hidden nodes, based on a detection system of the total received signal strength (TRSS) in the channel if it is above or below the detection threshold (Threshold Sensing ST). The channels, for which the TRSS is below ST, are marked as IDLE. The time during which the TRSS has dropped below the ST is noted for each channel. These channels are placed on a list of free channels. The rest of the channels are marked as busy

B. CSMA multi-channel with separate control channel

In [14], the authors propose a multi-hop multi-channel MAC protocol based on CSMA with two radio interfaces per node, a dedicated control channel for the controls frames exchange and a predetermined number of channels lower than the number of nodes in the network for data transmissions. Since the protocol is based on the CSMA system in presence of high traffics loads, it suffers from the problem of multi-channel hidden terminal. The authors extend the principle of 802.11DCF access method with several different structures. Before transmitting an RTS frame, the transmitter detects the carrier on all data channels and creates a list of available channels for data transmission, namely the channels of which the total received strength is below the carrier detection threshold. This list is included in the RTS frame of the transmitter node. After receiving the RTS frame, and before transmitting the CTS, the destination node creates its own list of available channels by carrier detection on all data channels. It then compares this list of available channels with that contained in the RTS frame. If there is in common available channels, the destination node selects a common channel and sends this information in the CTS frame. If there is not in common available free channels, the receiver does not send a CTS. Then the source is once again trying to send another RTS after a backoff. When the sending node receives the CTS frame, it transmits the data frame on the data channel indicated in the CTS.

The authors compare their multi-channel MAC protocol in terms of throughput and delay compared to the single channel access method 802.11. Based on their results, they conclude that it is a significant improvement in throughput and delay of their proposed method compared to the 802.11 method. The advantage of this protocol is that it performs a multi-channel multi-hop transmission, but in presence of a high traffic load, the protocol suffers from the hidden node problems and bottlenecks on the control channel.

C. EFCM

The authors of [16] propose a multi-channel MAC protocol with two interfaces on each node in the network, called EFCM (Efficient Flow Control with Multi-channels), they also assume that the time synchronization problem has been resolved. They modify the MAC layer of 802.11 and adapt it to a multi-channel multi-hop topology. Thus, they add a field at the RTS/CTS frames called multi-channel messages RTSM/CTSM, which transports information on the three channels. When a node wants to transmit data, it must first save the channel using the RTSM/CTSM frames, knowing that these latter cannot ensure a successful transmission in a multi-hop context, since it is necessary take account of the multi-channel hidden terminal problem. To solve this problem of multi-channel hidden terminal, the EFCM protocol divides a beacon interval into two periods: a contention period, and another for data transmission. For transmitting data, all nodes must compete for access to the channels during the contention period and then send their data frames during the transmission phase. We note that all channels are exploited in both periods (contention and data). The objective of this study also is to provide a control congestion system at the intermediate nodes in order to avoid the problem of delay and throughput degradation in the network, but also solve the multi-channel hidden node problem. So they will set different initial values to the backoff window size of each node according to their priority. The priorities are assigned based on data frames buffered at the intermediate node. Therefore, the source node has low priority, since congestion has the effect frame loss and degradation rate, congested node should have the highest priority.

The advantage of this protocol, in addition to the multi-hop transmission, it exploits all channels during the contention and data period. Also to avoid the throughput degradation, the protocol uses a congestion resolution system. Using supplementary information on the channels utilization, reduces the multi-channel hidden terminal problem therefore, multi-hop transmission is possible. But the disadvantage is that the MAC protocol EFCM imposes a cost by using two radio interfaces. We can also notice that, if the protocol always gives high channel access priority to intermediate nodes, it may create a starvation at the source nodes.

D. AMNP

Chen and *al* [15] propose a multi-hop multi-channel MAC protocol for Ad hoc called AMNP Multi-channel Negotiation Protocol for multi-hop mobile wireless networks in which each network node is equipped with a single radio interface that uses a single channel for control frames and the rest of the channels for data transmission. They extend the concept of control frames RTS/CTS used in the 802.11 standard where additional fields have been added to indicate the selected channel, as well as to specify the free channels or currently in use. Modified frames are called MRTS/MCTS to designate the multi-channel RTS/CTS. When a node wants to exchange data with another node, it first sends a MRTS frame to the receiver, this latter will compare the field SC (Selected Channel) of the MRTS frame with its channel status, that is to say, if the channel is free in its radio range, and then decide whether it can accept the request. If the preselected channel is also available on the receiver side, it accepts the transmission request and responds immediately by MCTS frame to the transmitter. Otherwise, the preselected channel cannot be used, since it is not free at the receiver side. The receiver will select another available channel based on the channel utilization state of the transmitter node, and respond with a MCTS frame to the transmitter in order to make the final decision. The MCTS frame contains the current data channels utilization state and the selected data channel information. The transmitter must return a MRTS frame to receiver in order to refresh the channel status at the transmitter side.

The advantage of AMNP compared with some multi-channel access methods which to achieve the goal of multi-hop multi-channel access use two radio interfaces. However AMNP uses a single radio interface providing sufficient information on the channel usage status, This reduces the multi-channel hidden terminal problem therefore facilitates the data frames exchange in multi-hop. The disadvantage of this protocol is the use of a single contention channel for the control frames exchange that may be a bottleneck in case of high traffic load.

Although the different multi-channel access methods that we have studied often have common structures However, some important characteristics allow to compare them. On the table 1 we note that all protocols use rendezvous before any data exchange. As we can also see that these rendezvous for most protocols are established on a specific channel (dedicated control channel).

TABLE I. COMPARISON OF PROPOSED MULTI-CHANNEL PROTOCOL

protocols	*Number of interfaces per node*	*Number of rendezvous*	*Number of hops*	*Principle of channel negotiation*
DCA	2	Single	Single-hop	Common control channel
Dedicated channel	1	Single	Single-hop	Common control channel
Split phase	1	Single	Single-hop	Common control period
Common hopping	1	Single	Single-hop	Common hopping sequence
Independent hopping	1	Multiple	Single-hop	Independent hopping sequence
CSMA multi-channel	1	Single	Single-hop	By carrier detection
CSMA multi-channel with dedicated control channel	2	Single	Multi-hop	Common control channel
EFCM	2	Multiple	Multi-hop	Common control period
AMNP	1	Single	Multi-hop	Common control channel

VII. CONCLUSION

In these studies that we have just presented, we note that the current proposed multi-channel access methods usually deal with single-hop multi-channel access. The multi-hop multi-channel concept was discussed with various constraints so that their implementation would not be easy. For a multi-hop transmission, the proposed multi-channel access methods often uses multiple interfaces to effectively control channels utilization; they also proceed sometimes to several exchanges controls frames, or use permanent broadcasts beacons to properly manage the various problems that occur during transmission. Contrariwise these exchanges frames controls and permanent broadcast beacons can dramatically penalize network performance in the presence of a high traffic load. We also note that the channels reservation by the methods that we studied occurs most of the time after a rendezvous on a predefined channel (using the concept of dedicated control channel or Split Phase). Multi-channel methods we have analyzed have often addressed the multi-hop context theoretically, for which we ask would it be easy to implement these methods in order to test their real performance in multi-hop. Another idea is to overcome negotiations of taking rendezvous that cause problems in multi-hop context because it is necessary to indicate to remote nodes the rendezvous taken in local. We then orient to the multi-hop multi-channel MAC without rendezvous.

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