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Towards a Packet Radio Network Single-channel Non-collision Multiple Access Protocol Based on Priority

Li-Xia LIU, Xiao-Hua QIU
Dept. of Information Engineering, Engineering University of CAPF, Xi'an, 710086, China
E-mail: wjllx939@tom.com

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Abstract: Multiple Access (MAC) protocol is a key issue in multiple packet radio network self-organization design. To address problems of hidden collision, adjacent collision and inability to effectively access with priority of multiple access protocol caused by multiple-hop, the paper brought out a novel Non-collision Multiple Access (NCMA) protocol that can effectively support access with priority. It also uses RTS/CTS dialog to arrange capture effect with CTS by deterministic slot, but no longer exist collision between RTS and RTS, RTS and CTS, CTS and CTS. The proposed protocol avoids problems of existing protocols that wasting channel resource for RTS/CTS collision in case of light load as well as throughput performance decrease as traditional CSMA under heavy load, thus significantly improving network resource utilization. Analysis result shows that NCMA can break limitation that existing multi-hop packet radio network cannot effectively networking and support priority. *Copyright © 2013 IFSA.*

Keywords: Packet radio network, Non-collision, Multiple access, Priority.

1. Introduction

Packet Radio Network (PRN) is a kind of distributed wireless packet data communication network based on radio. All nodes can be used as mobile router and rapidly networking dynamically. The PRN is simple and easy to set up. It not only has inherent feature that set to communication of radio, but also has unique functions as self-organization, self-adaption, self-healing and automatic multiple hop forwarding. Therefore, PRN can move with users, especially adapt to emergence maneuver occasions and moving communication applications. The network structure of PRN can be divided into two kinds of flat structure and hierarchy structure. In the flat network, all nodes are peer entities. Node is both data source and destination. It also acts as forwarding node of packets. Such networking manner is always applied in scenes with middle network size. It has advantages of simple and easy to manage. As to large network, cluster or zone is usually used to organize network nodes for simplifying network routing, network management. Thus, hierarchy network is formed. In the cluster-based network, network nodes are divided into two kinds, namely cluster head and cluster member. Cluster head is similar to base station in cellular system, which is responsible for communication control and coordination among nodes within cluster. In the MANET, cluster structure changes constantly. Typically, the formation and adjustment algorithm of a cluster is as follows [1]. Firstly, network nodes periodically exchange own status information. Secondly, if there is no cluster head in all neighbor nodes of a node, set it as head. Thirdly, if a cluster head is adjacent to another head, set node with less number or more neighbor nodes number as cluster head and another as member. It needs some network overhead to organize nodes with cluster, but make it easy to solve routing and network management problems in large-scale network. Therefore, it should adopt hierarchy networking structure to large-scale network. However, the flat structure is basis of hierarchy structure. The paper focuses on single multi-hop PRN with flat structure to propose a novel NCMA protocol supporting access with priority effectively and analyze its performance. The paper is organized as follows: section 2 analyzes problem to be solved; section 3 brings out single channel NCMA protocol and analyzes its performance; section 4 concludes our work.

2. Problem Analysis

2.1. Related Works

Multiple access protocol, namely medium access control (MAC) protocol, is a mechanism that multiple users in the network share same communication media. In the multi-hop PRN, a suitable MAC protocol directly impact on usage efficiency of every limited wireless resource. Currently, multiple access methods are mainly divided into three types as fixed allocation class, random access class and on-demand [1]. Fixed allocation, namely allocate resources to each user with pre-set resources, such as TDMA, FDMA and CDMA. It adapts to transmission of large amount continuous data and easy to implement. But the cost is a waste of resources. Random access obtains control on resource by competition as ALOHA, CSMA. It is effective to burst traffic and easy to implement. The disadvantage is collision. The on-demand allocates resources according to user requirements, such as appointment and polling. It is suitable for variable rate traffic but cause addition control overhead. To address this problem, main idea of currently designed MAC protocol is to combine these control manners effectively to achieve higher throughput, lower delay and less overhead at any traffic.

In the cellular system, commonly used MAC protocols are PRMA, DSA++, DTDMA and MASCARA [2, 3]. However, as there is no assistant from powerful base stations, these protocols cannot be implemented by distributed multi-hop PRN.

The most commonly used MAC protocol in distributed radio network is Carrier Sense Multiple Access (CSMA) protocol. For example, the R-NAD, P-NAD, H-NAD, DAP-NAD and RE-NAD [4, 5] in CNR and PRN with MIL-STD-188-220B are all based on CSMA protocol. However, as for half-duplex character of multiple-hop network structure and radio, even with carrier detection CSMA technique, two transmission nodes outside sense space may also encounter packet collision at public receiving node, which is usually called hidden terminal problem or hidden collision problem. It seriously affects success probability of each transmission, thereby greatly reducing throughput and delay performance of CSMA. In addition, a vital factor to channel utilization rate is exposed terminal problem or adjacent collision problem. The exposed terminal is node within source communication space but outside receiving communication area. Simulation result shows that if adjacent competition number $N \geq 6$, the probability of all adjacent nodes to collision exceeds 80 % [6]. Traditional method to solve hidden collision problem is to send busy signal with additional channel, and node monitor status of busy channel before transmission, which is Busy Tone Multiple Access (BTMA) protocol [7].

In order to solve hidden terminal problem without additional channel, many new protocols using Request-To-Send/Clear-To-Send (RTS/CTS) dialog to avoid collision were brought out, such as MACA [8], MACAW [9], IEEE 802.11 [10] and FAMA [11]. These protocols shorten collision interval that cause hidden terminal from packet length to short control packet length of RTS or CTS. Considering about multiplexing multi-channel of frequency hopping (FH) or direct sequence spread spectrum (DSSS), many manners that combines multiple channel and appointment to assist RTS/CTS solving hidden collision problem were proposed in recent years, such as Channel Hopping Multiple Access (CHMA) [12], Hopping Reservation Multiple Access (HRMA) protocol [13], DCCA [14], CARMA-MC [15] and MACA/CT [16]. These protocols usually randomly complete reservation on public channel and transmit traffic on multiple service channels, thus completely avoid possibility of collision on traffic channel. In addition, other researches focus on combination of fixed allocation and random competition to achieve better transmission under heavy burden, such as ADAPT [17], ABROAD [18] and HRMA [13]. The recent MAC protocol also supports QoS of multimedia traffic as CARMA-NTQ [19]. Node firstly appoint channel with RTS/CTS in the competition period to obtain non-competitive period. The packet in non-competitive period can be reserved to next appointment period. MACA/PR [20] is similar to CARMA-NTQ protocol. Receiving node answers after received each packet to notify its adjacent nodes whether it needs to transmit in next competition period. These programs derive from pure CSMA and require each node to construct channel status information according to appointment request in transmission packets. The Ref. [21] uses Black-Burst (BB) to compete reservation channel. The length of BB is related to priority and delay requirement so as to ensure delay needs of various real-time traffics to maximum extent. In addition, a radio network model whose carrier sense distance is two time of normal communication distance to eliminate hidden terminal in multi-hop structure, thus easily extending many protocols from single-hop to multi-hop situation.

2.2. Related Works Existing Problems

We can know from above conclusion that to multi-hop distributed radio network, regardless of working in single channel or multiple channel, the most commonly used methods in existing MAC protocols to avoid hidden collision and support QoS is to utilize RTS/CTS dialog reservation mechanism. Its characteristics and corresponding problems can be concluded as follows:

1) Existing protocols shorten collision interval caused by hidden terminal from packet length to RTS/CTS controlled packet length by RTS/CTS dialog. In other words, it cannot solve hidden collision or adjacent collision among RTS/RTS, RTS/CTS and CTS/CTS. It is because packet length of RTS and CTS is much shorter than that of packet, so collision between RTS and CTS has less negative impact on throughput of whole channel. Therefore, these protocols are still called Collision Avoidance (CA). In addition, for current tactical radios, as carrier detection, transceiver change and total wave propagation delay are always longer, the proportion of lead time and post time occupied in whole actual time is relatively bigger. At this moment, if collision of RTS/CTS cannot be overcome, these protocols will not be applied practically.

2) In the aspect of supporting effectively access with priority, total speaking, existing Mac protocol consider less, which is an important aspect that must be considered for tactical applications. Currently, there mainly depend on methods to set different level of access window, such as H-NAD, P-NAD, DAP-NAD of MIL-STD-188-220B [4] and IEEE 802.11 [10], as well as method to transmit appointment burst code with different length [21]. However, the former method also uses large amount of lower priority traffic to needlessly significantly increase delay even without higher priority access traffic. The latter method will also needlessly increase delay of larger priority traffic even without lower priority traffic competition.

3) Although design mainly with fixed allocation and assisted by random competition can better adapt to heavy load working, the channel utilization is not higher. It also causes large communication delay at light load. Fig. 1 shows ADAPT protocol [17]. Each node corresponds to a communication slot in the frame. If node *i* want to send data, it firstly appoint slot with RTS_{i1}/CTS_{i1}. Otherwise, other nodes will compete usage of slot DATA with RTS_{i2}/CTS_{i2}. At this moment, as long as two or more nodes compete RTS_{i2}/CTS_{i2}, collisions occur and corresponding DATAi waste. If number of RTS/CTS be added again, the control overhead and access delay also increase.

4) For QoS supporting multimedia traffic, the basic idea of multiple access is that node use similar RTS/CTS dialog in the competition period to appoint channel to obtain non-competitive interval, while packet transmission in the non-competitive period can be reserved to next period. The idea is worth for reference. It also illustrates that a non-collision RTS/CTS appoint mechanism support access with priority can thoroughly overcome problems of hidden collision and adjacent collision. It also avoids limitation of existing radio applications and improves channel access efficiency. The QoS of multimedia can also be effectively supported to ensure access with priority in tactical applications.

Therefore, the paper proposes a novel Non-Collision Multiple Access (NCMA) protocol continuing RTS/CTS reservation mechanism. It not only supports efficient access with priority, but also works on multiple channels with single channel or limited number channel.

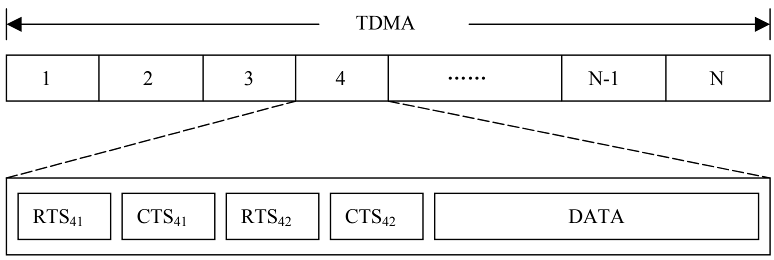

Fig. 1. Fame structure of ADPAT protocol.

3. Single Channel NCMA Protocol

3.1. Network Model

Assume each node in multi-hop PRN has only a half-duplex mode transceiver, which can work in single channel or limited multiple channels. Each node can carry out carrier sensing. Each node in the network has different ID as 1, 2, …, *N*, where *N* is also total node number in current PRN. The node ID can be obtained in case of usage or assigned in advance. Set transceiver conversion delay as τ_{RT}, carrier sense delay τ_{CD}, propagation delay τ_T. The transmission delay namely minimum access delay can be converted into T_r, T_c, T_d and T_a. The actual time for RTS, CTS, DATA and ACK packet are respectively $T_{rts} = \tau_P + T_r$, $T_{cts} = \tau_P + T_{cts}$, $T_{data} = \tau_P + T_d$ and $T_{ack} = \tau_P + T_a$. The access slot τ is transmission time of RTS packet $\tau = T_{rts} = \tau_p + T_r$. To facilitate discussion, other processing delay and packet post time can be ignored. Actually, the propagation delay τ_T is much less than transceiver conversion delay τ_{RT} and carrier sense delay τ_{CD}. The effective transmission time T_r of RTS packet is much smaller than lead time τ_P of each packet. Therefore, the actual access slot τ is close to minimum slot, namely lead time τ_P of each packet. Each node can achieve accurate synchronization among time slots with periodically self-organized package (SOP) or other means. Each node has own corresponding access mini-slots.

As to half-duplex multi-channel radio, we might assume multiple different direct sequence spread spectrum (DSSS) implement space division multiplexing of channel to improve channel utilization. Actually, the multiple channel manners can be implemented by different frequency hopping code and even multiple bands. At this time, available wireless resource can be divided into several parts. One of them serve as public channel to transmit reserved packets and others act as service channel for data packets transmission. When each node has not packet to transmit or receive, it sense public channel.

3.2. Minimum ID Slot Synchronization Algorithm

In the NCMA protocol, it is the key of ensuring NCMA access performance to retain synchronization of slots in all nodes. In the single-hop distributed network, the slot synchronization among nodes can be easily achieved by receiving packets from a node or carrier sensing. The deterministic arrange of slots in *N* nodes is shown in Fig. 2. The application example includes P-NAD and DAP-NAD protocols of MIL-STD-188-220B [4]. In the multi-hop distributed network, multi-hop structure make it is not easy to implement it. Although, there are GPs, mutual synchronization, quasi-synchronous, central control manners to solve slot synchronization problem under multi-hop status, they have certain restrictions and inconvenience. To this end, we propose a practical and reliable minimum ID number slot synchronization algorithm.

Typically, self-organization algorithm in network layer assigns each node with a different ID and earlier networking node can obtain a smaller ID. The minimum ID number slot synchronization algorithm means each node carry its own reference time in periodically broadcasting SOP and select node with minimum ID as synchronization reference node. If synchronization reference node suddenly cannot communicate for fault or destroyed in working, other nodes cannot receive control information from original reference node in the regulated time. When, the node with minimum ID in current network can be selected as new reference node. For nodes lost connections, it regulate that if not received any message in specified resign time, the node is regarded as resigned from network. Then, after current synchronization reference node sent it for long time, delete it from original slot queue. If original synchronization reference node restores communication in the resign time, after obtain reference of current network, the node then replace existing work as new reference node. As to new node, it usually obtains a larger ID from SOP. Then, the node sends current synchronization reference from original slot after too long a queue of messages adding a member slot. The above resign or recruit nodes being deleted or added from slot queue after certain time mainly because of reliable synchronized operation and prevent uncertainty caused by once SOP broadcasting and multi-hop forwarding. Fig. 3 shows deterministic slot arrange of multi-hop distributed PRN.

We can know from above method that the minimum ID synchronization algorithm has less control overhead and algorithm is concise. The network change caused by node failure, recruit, resign and movement has little effect on its synchronization result. Therefore, it has autonomous flexibility, highly coercive existence and ease of implementation.

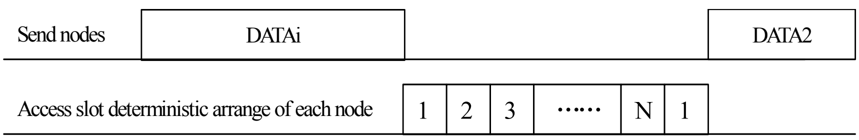

Fig. 2. Deterministic slot arrange of single-hop PRN.

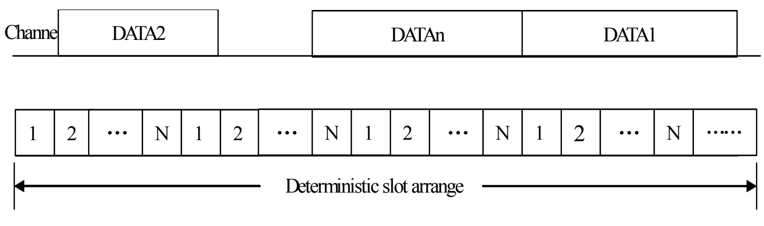

Fig. 3. Deterministic slot arrange of multi-hop PRN.

3.3. NCMA Protocol Supporting Randomly Access (R-NCMA)

The basic NCMA protocol of single channel is random NCMA, which is also the basis of following NCMA protocols. The form of R-NCMA is similar to IEEE 802.11 basically, which also adapts RTS/CTS dialog reservation and ACK mechanism as shown in Fig. 4. However, the essential difference with other access protocols using RTS/CTS is that R-NCMA overcomes collision among RTS/RTS, RTS/CTS and CTS/CTS by deterministically transmit RTS and capture effect of CTS.

The basic principle of R-NCMA is divide channel time into small infinite slots with period N with above deterministic slot arrange of multi-hop PRN. Each slot is assigned to N nodes uncertainly in turn. For example, slot 1 is assigned to node access channel whose ID=1, slot 2 assigned to ID=2 until slot N assigned to last node access channel whose ID=N. When one data transmission cycle ends and another cycle begin, set the first slot after end is FN, the node whose ID=FN is the first one has opportunity to access channel to transmit data in new cycle. If node FN+1 sense channel at former FN slot is idle, it indicates FN node has not data to transmit, the node FN+1 can access channel at FN+1 slot to transmit data, and so on. We can conclude the slot number F to compute Network Access Delay (NAD) of node ID=FN is as follows:

$$\begin{cases} F = TN - FN & TN \geq FN \\ F = N + TN - FN & TN < FN \end{cases}. \quad (1)$$

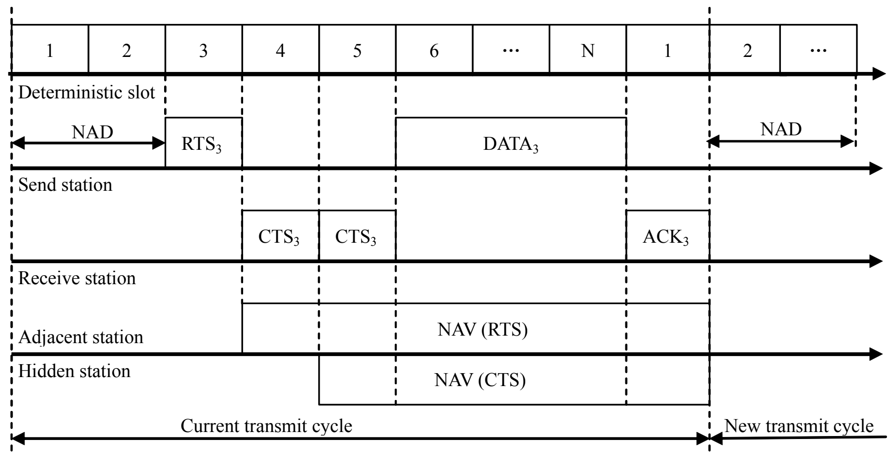

Fig. 4. Single-channel fair access R-NCMA.

At this time, if channel is still idle in the NAD and TN node has data to transmit, TN node transmit a RTS packet to next receiving node in the determined TN slot. Note that as each node only sends RTS at its own little slot, RTS/CTS will not collision. If RN node successfully receives RTS, it will immediately send a CTS packet longer than RTS normally. At this moment, CTS transmit is not necessarily at own slot, it may just occupy adjacent node slot for RTS transmission. If RTS/CTS collision cannot be overcome, hidden will not receive CTS, resulting in hidden node mistakenly believe channel be idle to transmit data, thus data of TN to RN easily to collision. The existing RTS reservation of TN is dummy, thus waste resources. To this end NCMA delicately extend CTS so that even any hidden node right send RTS, it can at least receive part CTS, thus overcoming collision of RTS/CTS. Furthermore, as the RTS/CTS collision been overcome, the TS/CTS collision is no longer exist. At this moment, if TN node successfully receives CTS, it can send DATA packet on channel. After receiver received DATA, it will immediately return an ACK to notify TN has correctly received DATA. Thus, begin from NAD to RTS and ACK, it is a data cycle. The previous cycle ends and a new cycle of the same process from the end ACK started again the next time slot.

In any transmission cycle, any adjacent node received RTS, CTS, DATA or ACK packet must maintain and update a timer. This timer is called Network Allocation Vector (NAV), which indicates that the remaining time when channel is occupied. Only when NAV reduce to zero can each node send information. In addition, in order to ensure fairness of nod access, longest cascade duration from RTS to ACK should avoid taking length of k×N slots, but may be equal to (k×N+1) slots, so that the next cycle can be guaranteed (TN+1) nodes rather than fixed nodes have priority access opportunities. According to the characteristics of DATA, ACK is optional in practical applications.

The notable feature of R-NCMA is that it completely overcomes hidden collision and adjacent collision problems. Even under heavy load, the channel throughput will not sharply decline like original way, but trains largest available throughput performance, so that the network resource utilization is significantly improved. In addition, collision overcoming among RTS/RTS, RTS/CTS and CTS/CTS also makes the RTS/CTS reservation multiple access protocol to practical application in existing tactical radio, which is of great practical significance to break the current tactical packet radio network cannot effectively restrict multi-hop networking.

3.4. NCMA Protocol Supporting Priority Access (P-NCMA)

Traditional priority access methods are mainly achieved by setting access windows with different access levels. For example, in the P-NAD of MIL-STD-188-220B [4], the first window with N little slots is used for emergency traffic, the second one for priority traffic and third one for ordinary traffic. Then the access delay of large amount of lower priority traffic is significantly increased needlessly. Different from traditional access methods, the P-NCMA protocol just base on R-NCMA to design with delicate declaration slot in advance so that access delay of traditional traffic and packet with priority can simply implement prioritized access by introducing overhead with 2-3 little slots. In addition, the prioritized method is also convenient for new node to networking.

Assume data packet is divided into three kinds of priority as Urgent (U), Priority (P) and Routine (R). Based on NAD of R-NCMA, the slot number F of NAD in P-NCMA can be computed as:

$$\begin{cases} F=2+TN-FN & TN \geq FN \\ F=2+N+TN-FN & TN<FN \end{cases}, \qquad (2)$$

Different from random NAD, the priority NAD always regard the former two access slots as fixed reserved slots. One reserved slot is U declaration slot and another one is P declaration slot as shown in Fig. 5. When one transmit cycle begins, any node with U or P packet firstly send a short U or P declaration frame in the reserved slot. Thus, any adjacent node with lower priority packets will at least receive a valid carrier sense single to know adjacent nodes have packets with higher priority to send, so it execute priority back-off strategy to ensure higher priority packets occupied channel. If there is multiple nodes send short U or P declaration frames on a U or P reserved slot, these nodes with same priority packets account fair but non-collision competition according to above mentioned random NAD manner. The whole process can be carried out according to R-NCMA.

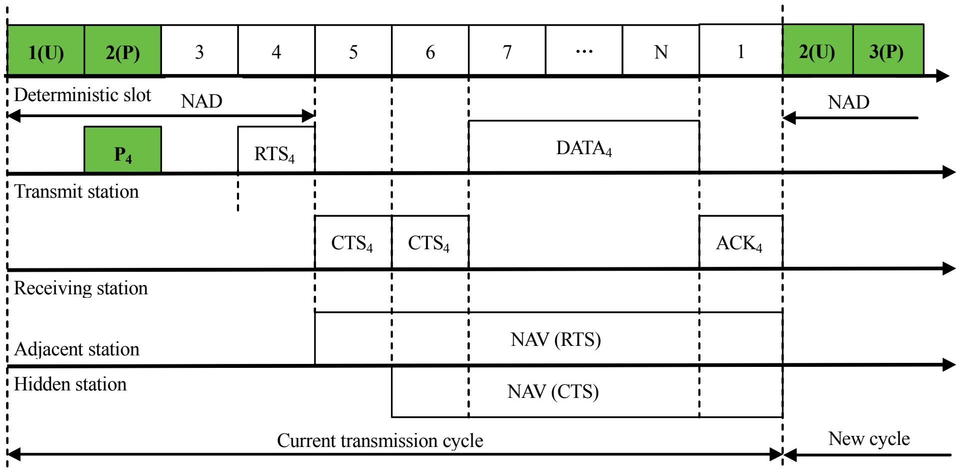

Fig. 5. Single-channel P-NCMA.

If priority voice packet is also introduced based on former three kinds of packets, the voice is also divided into three levels as U, P and R. The formula to compute NAD slot number of P-NCMA is:

$$\begin{cases} F=2+TN-FN & TN \geq FN \\ F=2+N+TN-FN & TN<FN \end{cases}, \qquad (3)$$

At this moment, a default reserved slot for Voice (V) is introduced to current two fixed reserved slots of U and P based on former NAD. When a node has voice packet to transmit, it will send a short V declaration frame on V reserved slot and determine whether send a short U or P declaration frame on U or P reserved slot according to priority of voice. It can know that its principle is similar to from data prior access basic principle. The difference is that here are six kinds of priority levels as shown in Table 1. As to QoS supporting real-time traffic, we can refer to existing methods, namely using RTS/CTS dialog in the competition period to clear reservation channel and obtain non-competition period, while packet can keep to next period be appointed in advance.

Table 1. P-NCMA priority levels with prior voice.

ID	V slot	U slot	P slot	Packet priority levels
0	0	0	0	Routine data packet
1	0	0	1	Priority data packet
2	0	1	0	Urgent data packet
3	0	1	1	Networking data packet
4	1	0	0	Routine voice packet
5	1	0	1	Urgent voice packet
6	1	1	0	Urgent voice packet
7	1	1	1	Reserved

Using P-NCMA protocol, it is also easily to ensure networking of new nodes. After one or more nodes obtained current synchronization basis from sensing, in the subsequent transmission cycle, continuously send a short networking declaration frame equal to U or P on two reserved slots of U and P. Thus, any adjacent nodes may at least receive a valid carrier sense signal with length of two slots to know at least one node to networking at this moment. Then, it executes networking back-off strategy to ensure node networking node compete channel with priority. Thereafter, new node randomly selects a NAD from N slots. If the channel is always idle in NAD time, it begins networking packet broadcasting. After adjacent nodes received networking packet declaration, they always send a SOP with used ID to new node. According to received SOP, new node can select a new bigger ID to notify networking declaration again. If current synchronization reference node received this networking declaration, it sends SOP to indicate how long it takes to add new member slot from original slot queue. Thus, all nodes in the network, including new networking nodes will synchronized add new members reliability to complete aces operation of new networking nodes.

4. Conclusion

The paper emphasizes on MAC protocol that play a fundamental role for multi-hop PRN. To address existing MAC protocols cannot overcome collision and effectively access problem caused by multi-hop, a novel NCMA protocol was brought out. With deterministic slot arrange and capture effect of CTS, adjacent collision and hidden collision among RTS and RTS, RTS and CTS, CTS and CTS are thoroughly overcome to significantly improve network resource utilization. Based on non-collision access, delicate design on prior declaration slot make it only needs to introduce 2-3 little slot overhead to original access delay to achieve prior traffic simply and effectively. It avoids traditional window difference methods significantly enlarge access delay of lower priority traffic. The access of non-collision, effective priority supporting and reliable slot synchronization breaks through restrictions of current TCN to effectively multi-hop networking and supporting prior traffics.

References

[1]. L. Kleinrock, On Some Principles of Nomadic Computing and Multi-access Communications, *IEEE Communication Magazine*, Vol. 38, Issue. 7, 2000, pp. 46-50.

[2]. G. Anastasi, L. Lenzini, E. Mingozzi, A. Hettich and A. Kraaling, MAC Protocols for Wideband Wireless Local Access: Evolution toward Wireless ATM, *IEEE Personal Communication*, Vol. 5, Issue 10, 1998, pp. 53-64.

[3]. I. F. Akyildiz, J. McNair, L. C. Martorell, R. Puigjaner, Y. Yesha, Medium Access Control Protocols for Multimedia Traffic in Wireless Networks, *IEEE Network*, Vol. 13, Issue 4, 1999, pp. 39-47.

[4]. Interoperability Standard for Digital Message Transfer Device Subsystems, *Military Standard, MIL-STD-188-220B*, January 1998.

[5]. *MIL-STD-188-220B*, Military Standard Appendices - Interoperability Standard for Digital Message Transfer Device Subsystems, January 1998.

[6]. S. Ni, Y. Tseng, Y. S. Chen, J. P. Sheu, The Broadcast Storm Problem in a Mobile Ad Hoc Network, in *Proceedings of the Fifth Annual ACM/IEEE International Conference on Mobile Computing and Networking*, Seattle, WA, August 1999, pp. 151-162.

[7]. F. A. Tobagi, L. Kleinrock, Packet Switching in Radio Channels: Part II The Hidden Terminal Problem in Carrier Sense Multiple-access and the Busy-tone Solution, *IEEE Transaction of Commun*ication, Vol. com-23, Issue 12, 1975, pp. 1417-1433.

[8]. P. Karn, MACA: A New Channel Access Method for Packet Radio, in *Proceedings of the ARRL/CRRL Amateur Radio 9th Computer Networking Conference*, Sept. 1990, pp. 134-140.

[9]. V. Bharghavan, A. Demers, S. Shenker and L. Zhang, MACAW: A Media Access Protocol for Wireless LANs, in *Proceedings of the ACM SIGCOMM'94,* London, UK, Oct. 1994, pp. 212-225.

[10]. C. R. Lin, M. Gerla, Adaptive Clustering for Mobile Wireless Networks, *IEEE Journal of Select Areas Communication*, Vol. 15, Issue 7, 1997, pp. 1265-1275.

[11]. J. J. Garcia-Luna-Aceves, C. L. Fullmer, Floor Acquisition Multiple Access (FAMA) in Single-Channel Wireless Networks, *ACM/Baltzer Mobile Networks Application*, Vol. 4, Issue 3, Oct. 1999, pp. 157-174.

[12]. A. Tzamaloukas, J. J. Garcia-Luna-Aceves, Channel-Hopping Multiple Access, in *Proceedings of the IEEE ICC'2000,* New Orleans, Louisiana, June 2000, pp. 415-419.

[13]. Z. Tang, J. J. Garcia-Luna-Aceves, Hop-Reservation Multiple Access (HRMA) for Ad-Hoc Networks, in *Proceedings of the IEEE INFOCOM'99*, New York, NY, USA, 1999, pp. 194-201.

[14]. V. Bharghavan, Performance Evaluation of Algorithms for Wireless Medium Access, in *Proceedings of the IEEE Performance and Dependability Symposium*, Raleigh, NC, Aug. 1998.

[15]. R. Garces, J. J. Garcia-Luna-Aceves, Collision Avoidance and Resolution Multiple Access for Multichannel Wireless Networks, in *Proceedings of the IEEE INFOCOM'2000*, Tel Aviv, Israel, Mar. 2000, pp. 595-602.

[16]. M. Joa-Ng, I. Lu, Spread Spectrum Medium Access Protocol with Collision Avoidance in Mobile Ad-Hoc Wireless Networks, in *Proceedings of the IEEE INFOCOM'99*, New York, NY, USA, Mar. 1999, pp. 776-783.

[17]. I. Chlamtac, A. Farago, A. D. Myers, V. R. Syrotiuk, G. Zaruba, ADAPT: A Dynamically Self-Adjusting Media Access Control Protocol for Ad Hoc Networks, in *Proceedings of the IEEE GLOBECOM'99*, Rio de Janeiro, Brazil, Dec. 1999, pp. 11-15.

[18]. I. Chlamtac, A. D. Myers, V. R. Syrotiuk, G. Zaruba, An Aaptive Medium Access Control (MAC) Protocol for Reliable Broadcast in Wireless Networks, in *Proceedings of the IEEE ICC'2000*, New Orleans, June 2000, pp. 1692-1696.

[19]. R. Garces, J. J. Garcia-Luna-Aceves, Collision Avoidance and Resolution Multiple Access with Transmission Groups, in *Proceedings of the IEEE INFOCOM'97*, Kobe, Japan, Apr. 1997, pp. 134-142.

[20]. C. R. Lin, M. Gefia, Real-Time Support in Multihop Wireless Network, *ACM/Baltzer Journal of Wireless Networks*, Vol. 5, Issue 2, 1999, pp. 125-135.

[21]. J. L. Sobrinho, A. S. Krishnakumar, Quality-of-Service in Ad Hoc Carrier Sense Multiple Access Wireless Networks, *IEEE Journal of Select Areas Communication*, Vol. 17, Issue 8, Aug. 1999, pp. 1353-1368.