A Trigger-Free Multi-user Full Duplex User-Pairing Optimizing MAC Protocol

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Abstract. In the high-density deployment scenario of the next generation wireless local area network (WLAN), the intensification of conflict makes spectrum utilization low. In order to improve the spectrum efficiency, the academia and industry will introduce Co-frequency Co-time Full Duplex (CCFD) technology into MAC as a key technology. However, the existing full-duplex Medium Access Control (MAC) protocol based on access point (AP) scheduling has the problem of low success rate in establishing full-duplex links. In order to solve this problem, a dynamic full-duplex link matching algorithm based on Binary-Graph is proposed, which is based on the author's earlier research on FD-OMAX [16]. This algorithm uses bipartite graph to establish the relationship model between full-duplex link and Resource Unit (RU). In each round of full-duplex transmission, AP establishes the optimal full-duplex link transmission based on the user's dynamic interference information on RU resources. In order to improve the success probability of establishing full-duplex links and spectrum efficiency, an enhanced trigger-free full-duplex MAC protocol, EnFD-OMAX, is designed on the basis of FD-OMAX protocol. The simulation results show that compared with FD-OMAX protocol, MuFuPlex protocol, OMAX protocol and FuPlex protocol, the throughput distribution of EnFD-OMAX protocol increases by 26.5%, 56.60%, 88.37% and 118.4% under saturated traffic. In high-density deployment scenarios, the probability of full duplex link to successful transmission and MAC efficiency are increased by 88.98% and 149.9% respectively compared with OMAX protocol.

Keywords: Next generation WLAN · MAC · CCFD · Bipartite graph

1 Introduction

Wireless Local Area Network (WLAN) has become the main carrier of wireless network services because of its low cost and flexible deployment. According to Cisco's analysis and forecast, the wireless business carried by WLAN will reach 49% in 2021 [1]. However, limited spectrum resources and low spectrum utilization have become a problem that hinders the development of WLAN. Therefore,

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how to improve the spectrum efficiency of WLAN system has become a hot research issue in industry and academia. IEEE 802.11 Standards Committee is working on the next generation of high-efficiency WLAN standards: IEEE 802.11ax [2], to further improve the data transmission efficiency and multiple access efficiency of WLAN.

IEEE 802.11ax standard introduces multi-user random competitive access and multi-user scheduling access into the MAC protocol. It combines two channel access modes to improve MAC efficiency. At the same time, the CCFD technology [3,4] is introduced into the next generation WLAN as the key technology to improve the spectrum efficiency under high-density deployment. In recent years, the maturity of self-interference cancellation technology [5–7] provides physical layer technical support for simultaneous full-duplex transmission at the same frequency. However, the traditional MAC protocol can not meet the requirements of full-duplex transmission. Designing an efficient full-duplex MAC protocol has become a hot research issue for researchers. H. Ah et al. proposed a frequency-domain coordinated full-duplex MAC protocol for AP scheduling [8]. This protocol reports channel information on designated subchannels by designated Station (STA). AP only schedules full-duplex link transmission, and the protocol STA has full-duplex capability. Document [9] proposes a multi-user full-duplex MAC protocol based on Orthogonal Frequency Division Multiple Access (OFDMA) with random competition in subchannels, which requires all users to have full-duplex capability. This protocol increases the complexity of equipment. Q. Qu et al. proposed a full-duplex transmission framework for the next generation WLAN [10], that is, AP has full-duplex capability, STA does not have full-duplex capability, and designed a full-duplex MAC protocol compatible with the standard protocol of IEEE 802.11. Subsequently, based on AP scheduling, multi-user full-duplex MAC protocol: MuFuPlex protocol [11], PCMu-FuPlex protocol [12] is designed and applied to the next generation of high-density deployment WLAN scenarios.

In summary, most of the existing full-duplex MAC protocols are focused on single-user random access and Scheduling-based multi-user access. However, the collision probability of simple random access protocol is high, which leads to low efficiency of MAC. Service collection based on scheduling multi-user MAC protocol results in high system overhead and poor real-time traffic transmission. Moreover, the existing Scheduling-based multi-user full-duplex MAC protocol has non-real-time link channel information, which results in low probability of successful transmission of full-duplex links. OMAX [13] first proposed the trigger-free upstream multi-user access MAC protocol for the next generation WLAN. The advantages of demand-based upstream multi-user access were expounded, and the feasibility was proved by theoretical analysis. Therefore, based on the framework of OMAX protocol, this paper designs a multi-user full-duplex OFDMA MAC protocol: EnFD-OMAX protocol, which is initiated by STA to establish full-duplex link transmission and report the channel state information of full-duplex link in real time. The protocol assumes that STA has the ability to detect subchannel power intensity. Through performance simulation, compared with FD-OMAX protocol, MuFuPlex protocol, OMAX protocol and FuPlex protocol, EnFD-OMAX protocol improves the system throughput distribution by 26.5%, 56.60%, 88.37% and 118.4%. In high-density deployment scenarios, the probability of successful transmission and MAC efficiency of full-duplex links are increased by 88.98% and 149.9% respectively compared with OMAX protocol.

The main contributions of this paper are summarized as follows:

(1) A dynamic full-duplex link pair matching algorithm based on bipartite graph is proposed. In each round of transmission, AP establishes the optimal full-duplex link pair according to the real-time dynamic interference information of STAs on RU to improve the success probability of full-duplex link.
(2) Based on the FD-OMAX protocol, an enhanced trigger-free multi-user full-duplex multiple access protocol, EnFD-OMAX, is designed, which supports upstream multi-user parallel channel access and real-time reporting of link status information. In order to realize the complete flow of the protocol, the corresponding Group Clear to Send (G-CTS) frame and Full-Duplex Clear to Send (F-CTS) frame structures are designed.
(3) Build NS-2 simulation platform, and simulate and verify the network performance and MAC efficiency of EnFD-OMAX protocol and FD-OMAX protocol, MuFuPlex protocol, OMAX protocol and FuPlex protocol.

The rest of this paper is structured as follows: Sect. 2 describes the full-duplex network scenario model and system model considered in this paper. Section 3 analyses the full duplex link pair matching scheme based on bipartite graph and the design of EnFD-OMAX protocol flow. Section 4 simulates and verifies the network performance of EnFD-OMAX protocol and existing MAC protocol. Finally, this paper summarizes.

2 System Model

A single Basic Service Set (BSS) is considered in the proposed protocol for the next generation WLAN and the performance of proposed MAC protocol is studied for different network scales with serious changes in channel state. As shown in Fig. 1, AP is located at the geometric center of the cell, STA is randomly distributed within the signal coverage of AP, and N semi-duplex STAs are associated with an AP with full duplex capability.

For the network scenario in Fig. 1, $UL = \{1, 2, \cdots K\}$ and $DL = \{1, 2, \cdots M\}$ are used to represent the upstream and downstream STAs set in a full-duplex transmission process, where $K, M \in [0, RU_{\max}]$, i.e. the total number of full-duplex link pairs established each time does not exceed the maximum RU, are determined by the upstream random access stage. According to EnFD-OMX protocol design, the target association in the set of uplink/downlink STAs is disorderly and $K \geq M$. Define the weights of the edges of UL_i and DL_j of any two vertices in the uplink/downlink STAs sets UL and DL as the signal-to-noise ratio strength of downlink DL_j in the case of uplink UL_i interference, as shown in Eq. (1).

$$\varGamma_{i,j} = \frac{P_{r,j}}{I_{i,j} + N_0} \tag{1}$$

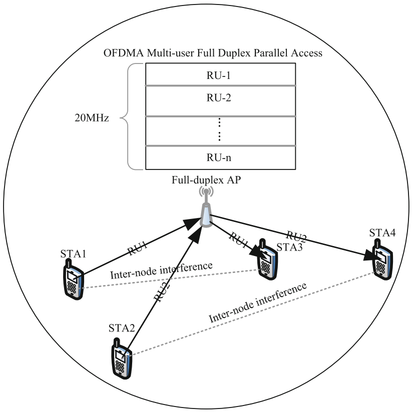

Fig. 1. Full duplex network scenario

Among them: $P_{r,j}$ is the downlink receiving power, N_0 is the additive white Gauss noise, $I_{i,j}$ is the interference power of uplink $I_{i,j}$ to downlink DL_j. According to Eq. (1), the weight $\varGamma_{i,j}$ of the edges of any two vertices in UL and DL can be calculated in one transmission, thus forming the correlation strength matrix. The larger the weight $\varGamma_{i,j}$ between vertices and edges, the higher the degree of target correlation; the lower the intensity of correlation. In this paper, in order to simplify the computational strength, $\varGamma_{i,j} \geq SINR_{throld}$ is considered to indicate that the objectives are interrelated, otherwise the objectives are not interrelated. According to the theory of bipartite graph matching, the optimal full duplex link pairs problem for one transmission can be modeled as a linear programming problem based on the correlation intensity matrix,as shown in Eq. (2).

$$\begin{cases} \max \sum_{i=1}^{M} \sum_{j=1}^{K} \varGamma_{i,j} H(i,j) \\ s.t \ \sum_{i} H(i,m) = 1 \quad m = 1, 2, \cdots M \\ \quad \sum_{j} H(n,j) = 1 \quad n = 1, 2, \cdots K \\ \quad \varGamma_{i,j} \geq SINR_{throld} \quad \forall i \in DL, \forall j \in DL \end{cases} \tag{2}$$

Among them: $H(i,j) = 1$ or 0, when $H(i,j) = 1$, it means that the two target vertices can form a matching relationship, and when $H(i,j) = 0$, it means that the two target vertices can not form a matching relationship.

3 Multiuser Full Duplex User Pair Optimizing MAC Protocol

The design of full-duplex MAC protocol for next generation WLAN can be divided into symmetric full-duplex MAC protocol and asymmetric full-duplex MAC protocol. Symmetric full-duplex MAC protocol requires full duplex capability of STA, while asymmetric full-duplex MAC protocol conforms to the trend of miniaturization and low complexity of the next generation WLAN terminal equipment. To meet the low complexity of WLAN terminal devices, the proposed protocol is asymmetric full-duplex MAC protocol. Firstly, according to OMAX upstream random competitive access mechanism, AP allocates RU channel resources and initiates downstream transmission requests according to the number of successful upstream access nodes. STA receives downstream requests to reply to the interference information of this upstream STA to this node. AP collects the interference information between this upstream and downstream STAs, and redistributes full-duplex link pairs based on Dichotomy theory to enhance the performance. Full duplex links improve the overall throughput of the system for the probability of successful transmission.

As shown in Fig. 2, EnFD-OMAX protocol is divided into three stages: upstream random competitive access stage, full-duplex transmission link pair establishment stage and full-duplex data transmission stage.

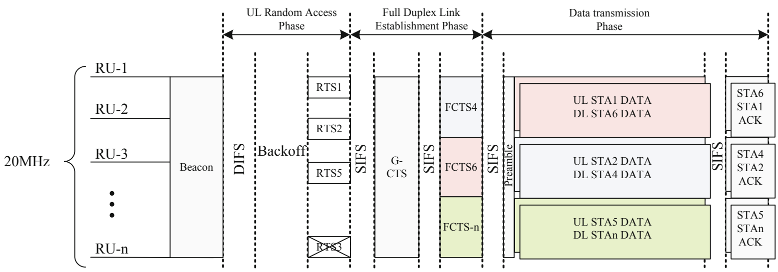

Fig. 2. A trigger-free multi-user full-duplex MAC protocol

3.1 Bipartite Graph-Based Resource Allocation Algorithms for Full Duplex Links

For the full duplex MAC protocol proposed in this paper, it can be understood as spectrum resource reuse of downlink transmission on upstream transmission RU. However, the EnFD-OMAX protocol is designed as an asymmetric full-duplex MAC protocol. During the establishment of a full-duplex transmission link pair, the upstream/downstream STAs set is a set of two sets of disjoint vertices. In order to better describe the maximum full-duplex link logarithm in a full-duplex transmission, a bipartite graph $G = \langle V, E \rangle$ is used to model it. For V is a set of node, it can be divided into two disjoint vertex sets A and B ;E is the edge set, and the vertex distribution associated with each edge belongs to A and B set. As shown in Fig. 3, let $A = UL$ be an upstream STA set and $B = DL$ is the downstream STA set, E set represents the frequency resource reuse relationship between the downstream STA and the upstream STA on the same RU. In this paper, only considering the optimization of full duplex transmission link pairs, Eq. (2) can be transformed into a bipartite graph for modeling, thus, the Hungarian algorithm [17] can be used as shown in Algorithm 1 to obtain the optimal solution for forming full duplex link pairs.

According to the protocol and bipartite graph algorithm proposed in this paper, it can be seen that in each iteration, the upstream STA contests for downstream STA to establish full-duplex transmission. At this time, the algorithm can only elect one downstream STA to establish full-duplex link. Therefore, the time complexity of the bipartite graph algorithm is $\Theta\left(n^2\right)$, and it has the advantage of low complexity.

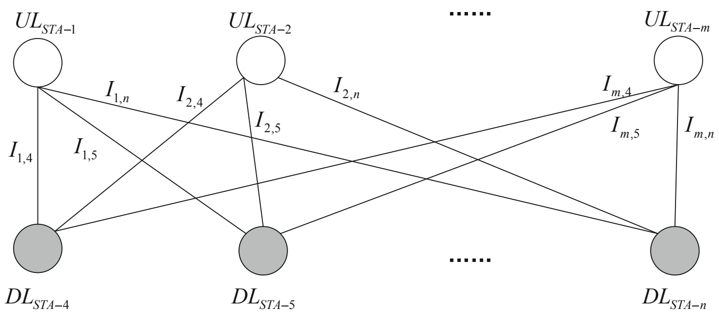

Fig. 3. Bipartite graph model

3.2 Uplink Random Access

In order to ensure the backward compatibility of the protocol, STA in BSS adopts the traditional DCF channel access mechanism, and the backoff process must be executed before data service is sent. When the channel is detected to be idle in DCF Inter-frame Space (DIFS), the backoff process is executed. STA with service delivery needs selects random values as backoff counts between Contention Windows (CW), and the backoff counts are reduced by 1 for each idle time slot. EnFD-OMAX protocol follows the OMAX protocol framework and adopts the time-frequency two-dimensional backoff mechanism [14] with the maximum resource block of 20 MHz bandwidth defined by the next generation WLAN standard. After backoff is completed, STA selects RU to send Request To Send (RTS) frames independently and randomly.

Algorithm 1. Full Duplex Link Pairs Matching Algorithm

Require: $UL = \{UL_0, UL_1 \cdots UL_k\}$, $DL = \{DL_0, DL_1 \cdots DL_h\}$; /* UL represents the set of uplink STAs,DL represents the set of downlink STAs*/
Ensure: $FD = \{< UL_{ulIndex}, DL_{dlIndex} >, \cdots\}$; /* Full duplex link pairs established by this transmission */

initialization
$M = k$,$N = h$
for $dlIndex = 0$ *to* $N - 1$ **do**
  Initialize all vertices of DL to unscanned
  if FDPair(dlIndex) **then**
    Loop the next value
  end if
end for
print /*************** FDPair (int dlIndex) start *******************/
function FDPair(dlIndex)
Mark the $STA_{dlIndex}$ as scanned
for $ulIndex = 0$ *to* $M - 1$ **do**

  if $STA_{ulIndex}$ isn't scanned and $SINR_{ulIndex,dlIndex} > SINR_{throld}$ **then**
    Mark the $STA_{ulIndex}$ as scanned
    if $STA_{ulIndex}$ isn't matched or The return value of FDPair($FD_{dlIndex}.DL$) is true **then**
      $< STA_{ulIndex}, STA_{dlIndex} >$ Uplink/Downlink Pairs Inserted into Set FD

      return true
    else
      return false
    end if
  end if
end for
return false
end function
print /*************** FDPair (int dlIndex) end ********************/

3.3 Full Duplex Link Establishment Process

First, each STA maintains an inter-node interference information table, dynamically updates the interference intensity after receiving RTS frames of other STAs; AP maintains a full-duplex link-to-information table, and dynamically updates full-duplex link-to-history information after receiving F-CTS frames. After the access of the upstream STA random competitive channel is completed, AP records the STA number of the channel successfully accessed on each RU. AP pre-selects downlink STAs that may form full-duplex links based on full-duplex links to historical information tables, and replies to G-CTS frames. As shown in Fig. 4, if there is no downlink link pair between the successful competitive access upstream STAs and the full-duplex link pair, the full-duplex transmission opportunity will be abandoned to enter the OMAX protocol transmission process; otherwise, the full-duplex transmission process will be entered and F-CTS frames will be received. AP receives F-CTS frames. Based on the latest inter-node interference information, full-duplex link pairs are redistributed to establish the algorithm by using full-duplex link pairs based on bipartite graph.

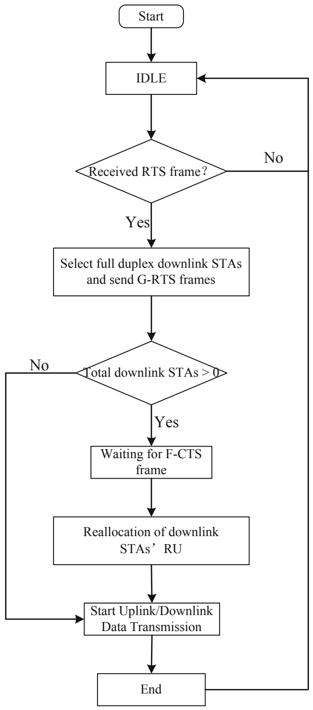

Fig. 4. AP establishes full duplex link pair processing flow

3.4 Frame Format

In EnFD-OMAX, RTS, DATA and ACK frames are defined by traditional WLAN standards. In order to improve the process integrity of EnFD-OMAX protocol, we need to extend G-CTS and F-CTS frames on the basis of CTS frames defined by traditional WLAN standard.

As shown in Fig. 5, the G-CTS frame contains downlink request receiving address and RU resource scheduling information, which takes up 2 bytes (16 bits), and each bit corresponds to one RU resource, i.e. it can support up to 16 full-duplex link allocation information. When RU resource scheduling bit position 1, it means that the upstream STA transmits DATA frames on this RU, and the downstream STA replies to F-CTS frames on this STA.

Octets	2	2	6	6	2		6	6	2	4
	Frame Control	Duration	Uplink RA 1	Downlink RA 1	RU 1	......	Uplink RA n	Downlink RA n	RU 1	FCS

Fig. 5. G-CTS frame structure

As shown in Fig. 6, the F-CTS frame adds all the upstream STA address information in the G-CTS frame, and corresponds to the interference intensity information of the STA to the node. The interference intensity domain is 2 bytes long (16 bits).

Octets	2	2	6	2		6	2	4
	Frame Control	Duration	Uplink RA 1	Interference intensity-1	......	Uplink RA n	Interference intensity-n	FCS

Fig. 6. F-CTS frame structure

4 Performance Evaluation

4.1 Simulation Configuration

In order to verify the network performance of EnFD-OMAX protocol, a link-system network simulation platform is built under NS2 network simulation software. The simulation scenario is set as a single basic service set (BSS) scenario, that is, AP is located in the center of the simulation area; STA is randomly distributed in the region, and the number of STAs increases gradually from 10 to 50 with a growth base of 5. The simulation time is 50 s, and the final simulation result is the average of 5 repeated simulation results. In order to fairly verify the network performance of the proposed protocol and the existing protocols, the traffic of AP and STA is set to saturated traffic, and there is a data packet waiting to be sent at any time. The draft 802.11ax protocol divides the 20 MHz channel into nine RUs by OFDMA technology, allowing simultaneous access of nine STAs to parallel channels with different RU resources. Channel is a time-varying channel model. Other network parameters are set as shown in Table 1.

Table 1. Parameters

Parameters	Value
Preamble time	20 us
Control packet PHY rate	6 Mbps
DATA packet PHY rate	54 Mbps
$CW_{\min}$	15
$CW_{\max}$	1023
$DIFS$	34 us
$SIFS$	16 us
$Slot$	9 us
$RU_{\max}$	9
$SINR_{Throld}$	3.16 dB
Channel bandwidth	20 MHz
TXOP	3 ms

4.2 Simulation Results

In order to verify the performance of EnFD-OMAX protocol, this paper compares the network performance with OMAX, FuPlex and MuFuPlex.

The total system throughput is an important performance index to measure the design of MAC protocol. To fairly verify the FD-OMAX protocol, MuFuPlex protocol, OMAX protocol, FuPlex and EnFD-OMAX protocol, both upstream and downstream are set to saturate traffic, ensuring that at least one packet needs to be sent at any time. As shown in Fig. 7, the total throughput of the proposed EnFD-OMAX protocol is 26.5% higher than that of the FD-OMAX protocol system, because the optimal pairing algorithm of full-duplex transmission link pairs based on bipartite graph is adopted in each full-duplex establishment process. FuPlex protocol is lower than OMAX protocol in total system throughput, which proves that the performance of multi-user access protocol is obviously due to single-user access protocol. MuFuPlex protocol and EnFD-OMAX protocol are multi-user MAC access protocols. With the increase of deployment nodes, system throughput tends to be balanced, while EnFD-OMAX protocol has obvious advantages in system throughput.

In full-duplex network system, the success probability of full-duplex transmission link is an important performance index to measure the design of full-duplex MAC protocol. Successful transmission probability of full duplex link directly affects the total throughput of the system. As can be seen from in Fig. 8, the EnFD-OMAX protocol combines real-time reporting of full-duplex link information with full-duplex link history information, and the full-duplex link allocation algorithm based on the bipartite graph is reconfigured twice with full-duplex link pairs, which greatly improves the probability of successful transmission of full-duplex links. At a certain degree of node size, the probability of success is more than 80%.

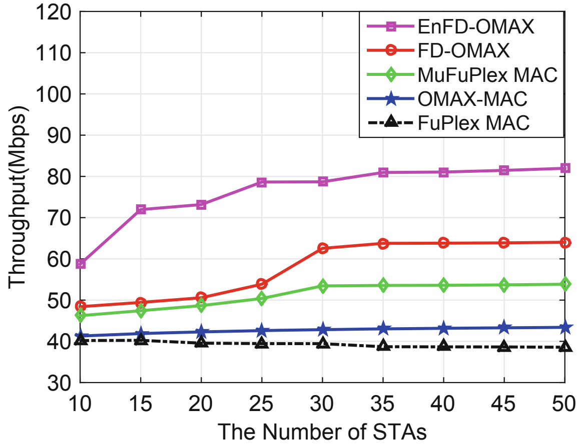

Fig. 7. System effective throughput (saturated traffic)

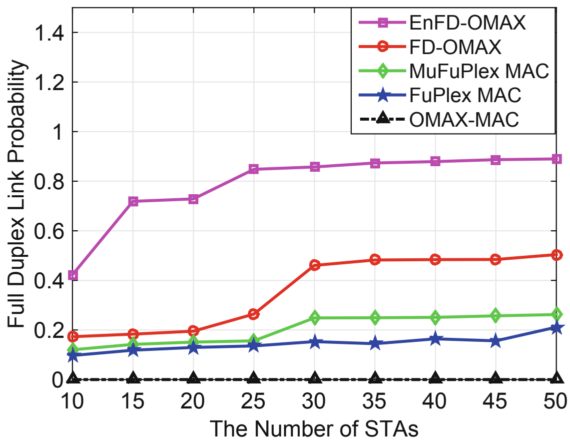

Fig. 8. Full duplex link probability

MAC efficiency has been considered as an important indicator to evaluate the performance of MAC protocol design in academia and industry [15]. CCFD is an important means to improve MAC efficiency. As shown in Fig. 9, the efficiency of multi-user MAC protocol is higher than that of single-user MAC protocol, while the EnFD-OMAX protocol improves significantly the efficiency of MAC due to the improvement of the probability of successful transmission of full-duplex links, especially in large-scale network scenarios, which is in line with the next generation of WLAN high-density network deployment scenarios.

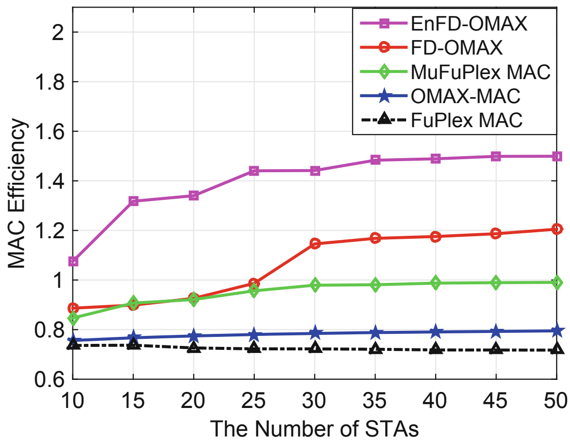

Fig. 9. MAC efficiency

5 Conclusion

In view of the low probability of success of full-duplex link establishment under the high-density deployment of the next generation WLAN, this paper proposes a trigger-free multi-user full-duplex MAC protocol initiated by the STA competitive access channel to report the full-duplex link information in real time, and optimizes the maximum full-duplex transmission by referring to the full-duplex link allocation algorithm based on the bipartite graph. The simulation results show that compared with FD-OMAX protocol, MuFuPlex protocol, OMAX protocol and FuPlex protocol, EnFD-OMAX protocol improves the system throughput distribution by 26.5%, 56.60%, 88.37% and 118.4%. In high-density deployment scenario, the probability of successful transmission and MAC efficiency of full duplex link are increased by 88.98% and 149.9% respectively compared with OMAX protocol. Follow-up research will optimize the allocation of full-duplex spectrum resources, so as to further improve system throughput.

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References

1. Cisco. Cisco Visual Networking Index: Global mobile data traffic forecast update 2016–2021. Cisco White Paper (2017)

2. IEEE Draft Standard for Information Technology - Telecommunications and Information Exchange Between Systems Local and Metropolitan Area Networks - Specific Requirements Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment Enhancements for High Efficiency WLAN. In: IEEE P802.11ax/D4.0, February 2019, pp. 1–746, 12 March 2019
3. China Telecom: IEEE P802.11 Wireless LANs Proposed TGax draft specification. https://mentor.ieee.org/802.11/dcn/13/11-13-0765-02-0hew-co-time-co-frequency-full-duplex-for-802-11-wlan.ppt
4. Wang, P., et al.: IEEE P802.11 wireless LANs proposed TGax draft specification. https://mentor.ieee.org/802.11/dcn/18/11-18-1588-02-00fd-prototype-of-full-duplex-for-802-11.pptx
5. Shende, N.V., Gürbüz, Ö., Erkip, E.: Half-duplex or full-duplex communications: degrees of freedom analysis under self-interference. IEEE Trans. Wireless Commun. **17**(2), 1081–1093 (2018)
6. Han, S., Zhang, Y., Meng, W., Chen, H.: Self-interference-cancellation-based SLNR precoding design for full-duplex relay-assisted system. IEEE Trans. Veh. Technol. **67**(9), 8249–8262 (2018)
7. Hong, S., Mehlman, J., Katti, S.: Picasso: flexible RF and spectrum slicing. In: ACM SIGCOMM Conference on Applications (2012)
8. Ahn, H., Lee, J., Kim, C., Suh, Y.: Frequency domain coordination MAC protocol for full-duplex wireless networks. IEEE Commun. Lett. **23**(3), 518–521 (2019)
9. Wang, X., Tang, A., Huang, P.: Full duplex random access for multi-user OFDMA communication systems. Ad Hoc Netw. **24**, 200–213 (2015)
10. Qu, Q., Li, B., Yang, M., et al.: FuPlex: a full duplex MAC for the next generation WLAN. In: 11th EAI International Conference on Heterogeneous Networking for Quality, Reliability, Security and Robustness. IEEE (2015)
11. Qu, Q., Li, B., Yang, M., et al.: MU-FuPlex: a multiuser full-duplex MAC protocol for the next generation wireless networks. In: Wireless Communications & Networking Conference. IEEE (2017)
12. Qu, Q., Li, B., Yang, M., Yan, Z.: Power control based multiuser full-duplex MAC protocol for the next generation wireless networks. Mob. Netw. Appl. **23**(4), 1008–1019 (2017). https://doi.org/10.1007/s11036-017-0966-y
13. Qu, Q., Li, B., Yang, M., et al.: An OFDMA based concurrent multiuser MAC for upcoming IEEE 802.11 ax. In: Wireless Communications and Networking Conference Workshops (WCNCW), pp. 136–141. IEEE (2015)
14. Kwon, H., Seo, H., Kim, S., Lee, B.G.: Generalized CSMA/CA for OFDMA systems: protocol design, throughput analysis, and implementation issues. IEEE Trans. Wireless Commun. **8**(8), 4176–4187 (2009)
15. IEEE Technical Presentations: Analysis on IEEE 802.11n MAC Efficiency. IEEE 802.11-07/2431r0
16. Peng, M., Li, B., Yan, Z., et al.: Research on a trigger-free multi-user full-duplex MAC protocol. Submitted to Journal of Northwestern Polytechnical University
17. Wright, M.B.: Speeding up the Hungarian algorithm. Comput. Oper. Res. **17**(1), 95–96 (1990)