ANALYZE GAIN OF DISTRIBUTED MULTICHANNEL MANUFACTURING AUTOMATION PROTOCOL NETWORK

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Abstract

Two reasons for high data rate LANs are a dramatic increase in computer processing power over the last few years and an enormous increase in the volume of stored and processed data [1]. The DMMAP (Distributed Multichannel Manufacturing Automation Protocol) network is a high speed local area network, which medium access control uses analogous token-passing bus protocol. It is fully compatible with token-passing bus network. There are two problems in DMMAP. The first is how to manage many simultaneously received tokens, and the second is how to decide which Medium Access Control (MAC) frame should be transmitted first, to make the system function smoothly. This paper has solved these problems by extending the length of response window and keeping the token for the highest priority data. We found that the DMMAP can expand the total network bandwidth with increase inexpensive Lower MAC (LMAC), and the relation will like linear growth in channel number below one hundred.

From the above analysis, we found that the extended bandwidth is not proportional to the channel number. The reason of this phenomenon is that the overhead of the response window is proportional to increased channel number, so the curve of service time versus channel number of DMMAP is a parabola, as fig 12. In this paper, we have analyzed this phenomenon and give (1) the formula of the gain of DMMAP compared with Manufacturing Automation Protocol (MAP), (2) upper bound and lower bound of response window size.

Introduction

The MAP network uses highly reliable cable television equipment, which is available off-the-self from numerous vendors. It is more deterministic than IEEE 802.3, and has excellent throughput and efficiency at high load [3]. However advances in computing and other technologies have produced a significant and rapid increase in the demand for new co mmunication services. The need of network bandwidth will enormously increase in the future. In this paper, we will introduce a high bandwidth network that is compatible with MAP. Section 1 surveys the system architecture. The phenomenon "token overlay" and the consideration of MAC control frame's priority will discuss in section 2. Section 3 analyzes the slot time and the response window of DMMAP network. The speedup gained on service time of DMMAP network is analyzed in section 4.

1. System architecture.

The DMMAP network is a high speed local area network, which medium access control uses analogous token-passing bus protocol (IEEE 802.4). Its physical topology is a linear or tree-shaped cable onto which the stations are attached. Logically, the stations are organized into many independent rings network as fig 1.[2] The DMMAP provides a dynamic assignment mechanism that connects the working group stations together, it will shorten the response time of transmitting frame in that specific group channel, since there are fewer stations attached to the channel.

The IEEE 802.4 standards does not directly correspond to the ISO/OSI model. IEEE 802.4 breaks the data link layer into the media access control (MAC) and the logical link control (LLC) sublayers [5]. In a multichannel network, each channel needs a private MAC device to service its medium access control, so the IEEE 802.4 model is unadopted. Hence we break the MAC sublayer of IEEE 802.4 standard into an upper

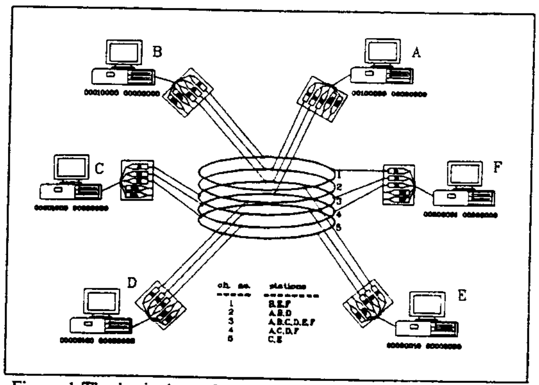

Figure 1.The logical topology of DMMAP network.

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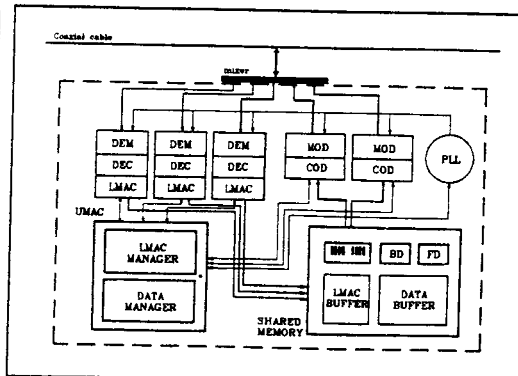

Figure 2. The Architecture of DMMAP station's network interface

MAC (UMAC) and many Lower MAC (LMAC) sublayers. The former provides the services of scheduling frame according to its priority, the latter provides the medium access control sevices of IEEE 802.4. Therefore we increase the number of the DMMAP receivers to equalize with the number of channels, but bases on electric power, magnetoelectric distrubance, heat, and cost sake [2], we just adopt two transmitters only, a data frame transmitter (DTX) and a MAC frame transmitter (CTX).

The architecture of DMMAP station consists of an UMAC, many LMACs and receivers, a shared memory, a CTX, and a DTX, as shown in fig 2. Although the channels of DMMAP are fully independent of each other, but in a station, there are many LMACs will communicate with the UMAC, so the expanded bandwidth will not grow linearly. The UMAC sublayer of DMMAP is consist of data manager (DATAM) and LMAC manager (LMACM), the former is used to manage the data packets from or to LLC. The packets will be assigned to transmit queues according to their priority. The latter is used to arrange the simultaneous arrival of MAC frames which from LMACs to the CTX. It will make the urgent MAC frame to transmit first.

2. "Token overlay" and MAC frame priority.

The priority policy of data frame of DMMAP allows the more important messages to be transmitted first, like as the MAP priority scheme, except that the station had received more than one token at the same time. Generally, a station transmits its data frame need only of one token at a time, so the DATAM should pass the other tokens to its successors through their channels. When there are more than one arrival token, the DATAM will inspect which token can service the highest priority data frame in transmitting queue, then keep the token and send the other tokens back to their channels. For example in figure 3, we consider the station C on the fig. 1 network, it had gotten the token of channel 5, and was transmitting the data frame of queue 4 at time X1. After the time X1, the LMAC3 has received the other token from channel 3 that can service the data frame of queue 6. The DATAM inspects those tokens, and sends the token of channel 5 back to its channel. This phenomenon of multiple tokens simultaneously arrived at a same station is called "token overlay" that will shorten the total bandwidth. A station on DMMAP network, which channel number is M, should increase its bandwidth times M, but the token overlay that makes some token passed to successor before its timer expired shortens this time to k, as fig. 4.

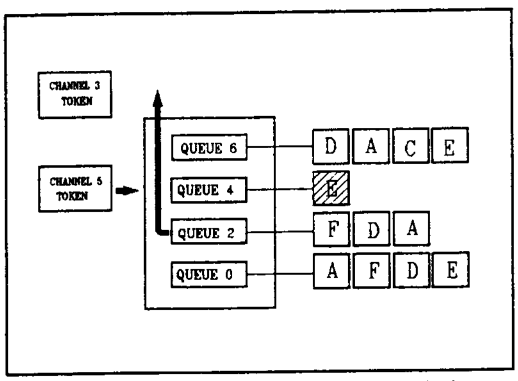

Figure 3. A drama of multiple simultaneous arrival token.

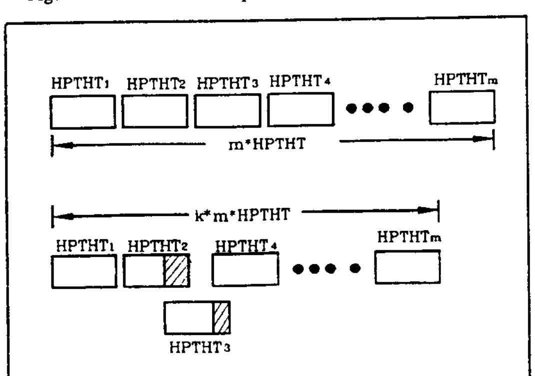

Figure 4. The example of token overlay.

In this section, we will analyze the effect that the MAC frames have been delayed too long, then according to that effect to make a decision of priorities of MAC frames. First, we analyses the effect of token frame delay in waiting queue. If a token stays in the waiting queue too long, it will lose the real time characteristic of network, and make the idle timer of channel to be time-out. That will cause some stations to mistake that token has lost or the token holder has gone down, then a channel initialization process will be generated. Second, if the set_successor frame has been delayed too long, (1) it may lose to response the solicitation of solicit_successor_1 frame that will lose the chance of entering the channel, this is no matter of the network. This frame should be dropped by the LMACM when it has listened to the channel is non-silence. (2) It may lose to response the asking of the who_follows frame in time, and makes an unnecessary reinitialation, that will take some overhead to network. (3) It may lose to response the solicitation of solicit_successor_2 frame that will make the token to give up maintain the logical channel, that will take some overhead to network. Third, If the solicit_successor_1 frame has been delayed too long, it will make some performance problem as that the token holder waits to transmit and takes the token with it. This frame should be dropped by the LMACM when the ring maintenance timer is time-out. Fourth, If the resolve_contention frame has been delayed too long, the station will give up the solicitation of solicit_successor_1 frame and pass the token to its successor when the ring maintenance timer is time-out, this is no matter

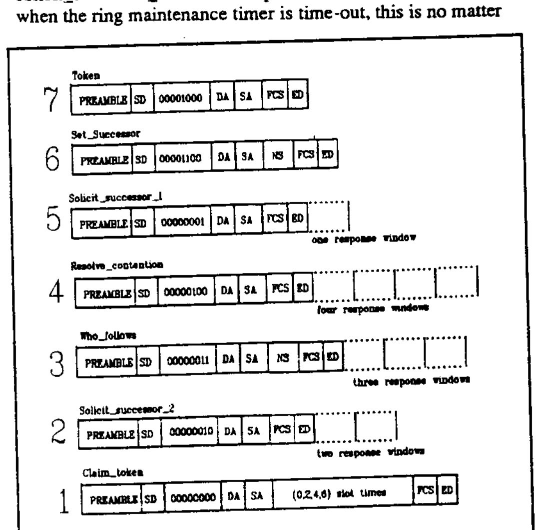

Figure 5. The priority of MAC frame.

of the network. Fifth, the who_follows frame, solicit_successor_2 frame, and claim_token frame are special frames, and seldom appear in the network, if that frames have been delayed too long, that will not matter of network. From above analysis and according to the operation frequency of MAC frame, we give a MAC frame priority table.

In 1985, IEEE Computer Society ([10], p50) has described the MAC frame formats of the MAP, it is same as DMMAP's. These frame formats consist of all field contents and the needed number of response window of frame. The priority and frame length of MAC frames are shown in fig. 5. We have divided the MAC frame length into three classes, the first class is including preamble, start delimiter (SD), frame control (FC), destination address (DA), source address(SA), frame check sequence(FCS), and end delimiter (ED) fields, this class length is denoted by T_1. The token, solicit_successor_1, resolve_contention, and solicit _successor_2 frames are belong to this classes. The second class contains the fields of first class and the next station address field of frame, it is denoted by T_2. The set_successor, who_follows frames are belong to it. The last class is claim_token frame, its length contains the length of first class and multiples of (0,2,4,6) slot time lengths in data field, it is donted by (T1 + n Tsl), n = 0,2,4,6.

3. Slot time and response time.

The slot time is used to refer to the maximum time any station need wait for an immediate medium access level response from another station, as fig 6. It is defined in [4] as below :

Slot time = 2 (transmission_path_delay + station_delay) + safety_margin

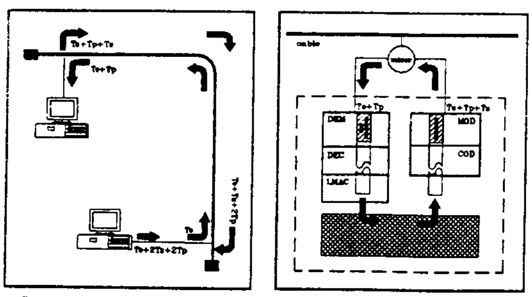

Figure 6. The propagation delay and station processing time of slot time.

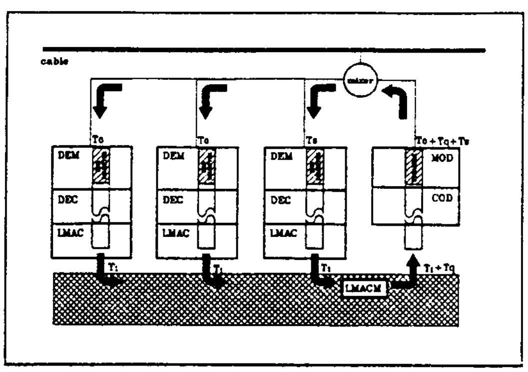

Figure 7. The station processing time of response window.

$$Tsl = 2\,(Tp + Ts) + Tf = 2\left(\frac{L \cdot D}{8 \cdot V} + T_s\right) + Tf \qquad (1)$$

The transmission_path_delay Tp is the worst case delay which transmissions experience going through the physical medium from a transmitter to a receiver. The station_delay Ts is a time from the receipt of the last bit of the received ED at the receiving station's physical medium interface to the first bit of the immediate_response frame onto the physical medium by that station's transmitter. The safety_margin Tf is a time interval no less than the time of sending one bit. According above definition, the slot tume can be easily calculated at equation (1), that transmission_path_delay Tp is equal to the length of maximum transmission path L meters times transmitting rate D octets per second and divided it by the velocity of electric wave V meters per second, then normalized by the factor 8 bits per octet. These parameters are unchanging in an operating network, so the size of slot time is a constant value when a network is installed.

A response window is a controlled interval of time after transmission of a MAC_control frame in which the station sending the frame pauses and listens for a response. It defines the time interval during which a station will hear the beginning of a response from another station [4]. This interval has defined as one slot time long in IEEE 802.4 standard, but it is not enough for the DMMAP response window, because it hasn't considered the queued time of the MAC frames in LMACM of the station when multiply MAC frames had been submitted simultaneously as fig 7. Therefore, the response window of DMMAP should be equal to the sum of slot time and queued delay time in LMACM, as below:

Response window = slot_time + queued_delay_time

$$= 2\left(\frac{L \cdot D}{8 \cdot V} + Ts\right) + Tf \; + \text{queued\_delay\_time}.$$

The response window is a function of channel numbers, active station numbers, network throughput, and setting parameters. Hence response window changes when one of these parameters changes. However the response window should be a determinate value since it is a system parameter that will be setting in network installation. So we should infer the range of response window to analyze the gain of service time of DMMAP.

To derive an upper bound of the response window, we firstly introduce the channel_idle timer of LMAC that likes as the bus_idle timer in IEEE 802.4 [4]. The timer will begin to count when its LMAC inspected the channel that the LMAC always monitors is idle. When channel_idle timer Tout expired, the LMAC sends a claim_token frame to start the initialization algorithm that will take some overhead of network bandwidth. To avoid this, we must guarantee the transmission time of longest frame, resolve_contention frame, that comprises its response windows should shorter than the time out Tout. So the upper bound on response window is

$$\text{Response window} \leq \frac{T_{out} - T_1}{4} \qquad (2)$$

The lower bound on response window size is the sum of slot time and the worst case LMACM queueing time Tq. In order to analyze the worst case queued time, we establish a model as below: There are N active stations attached to bus which has been breaked into M channels by frequency division multiplexing (FDM) technique, and every station has M LAMCs to interface that channels, so every channel is fully connected with all active stations. The notation about this model has defined as follow: A ≡ the station address length in the network. Pk ≡ the mean of bandwidth that token overlay has happened divide to the total bandwidth that token overlay does not happen. Tf ≡ the safety margin of slot time.

The drama of the worst case is that there are M submitted MAC frames in the LMACM at the time Ti, and their priorities are six above, as fig 8. We assume that token frame and set_successor frame could not be delayed for performance reason. In this figure, the highest priority submitted MAC frame is the claim_token frame of channel 2 that has a maximum (six slot time) length in its data field. It had increased its priority after six times transmitted frames of LMACM. The lowest priority LMAC at the channel M has a set_successor frame that will make a unnecessary reestablish channel process if it has not responsed to the who_follows frame in time. The priority of that set_successor frame will increase to seven after the claim_token frame has been sent, and it will be transmitted after the frames on other M-1 channels had been sent by LMACM, because the priority of new submitted frames of other channels will be lower than its priority at the time Ti + 2. The worst case queued time is (M - 1) T2 + (T1 + 6 Tsl), so the lower bound on response window has found as

$$\text{Response window} \ge (M-1)\,T2 + (T1 + 6\,Tsl) + Tsl = (M-1)\,T2 + T1 + 7\,Tsl. \qquad (3)$$

From above equation, we find the response window is growth when the channel number M, the transmission_path, the station_delay,or the transmitting rate are growth.

4. Service time and its speedup.

The token rotation time of channel j (TRTj) is the time from the last time the station had the token to when the station receives the token again. The TRT consists of the service time and token passing time of all active station on that channel. The service time Sij of channel j in station i is a time that has expired since the LMACj has the channel's token and sent any higher priority waiting data frames up to it transmits MAC frame. The passing token time Pij is the time that channel j in station i transmitted MAC frame. The relation of these time is show below:

$$TRT_j = \sum_{i=1}^{n} (S_{ij} + P_{ij}) \qquad (4)$$

By setting the Sij of equation (4) to zero when all stations on channel j have no data to transmit, the lower bound is affirmed

as: $$TRT_j\,(\text{lower}) = \sum_{i=1}^{n} P_{ij} \qquad (5)$$

The passing token time Pij is a variable value that consists of the time necessary to transmit MAC frames in the station i on the channel j, and n is the number of station on channel j. That length of Pij could be the time of a transmitting and propagating token frame when the token pass has been completed successfully by station i. However it also could be the time of some transmitting, propagating, and queued MAC frames when there are the case of contention or any problem in that channel. Hence the length of Pij will be altered by the status of channel that will make the analysis to complicate, so we assign the mean of its length to one response window for easy analysis.

The upper bound of TRT is the time that substitues the time Sij in equation (4) by the high priority token hold time (HPTHT) when all station i on the channel j always have data to transmit. The time TRTmax is a parameter that was setted during installation process; it guarantees the token will return before it expired.

$$TRT_j\,(\text{upper}) = \sum_{i=1}^{n} (HPTHT + P_{ij}) = TRT_{max} \qquad (6)$$

The lower bound of service time is equal to zero when all station on channel j have no data to transmit. The upper bound of service time is the upper bound of TRT substract the time of passing token.

$$0 \le S_{ij} \le \frac{TRT_{max}}{N} - (M-1)T_2 - T_1 - 7T_{sl} \qquad (7)$$

The total service time of station i that consists of M channels is a multiple of Sij, but it should be times a probability factor of token overlay Pik.

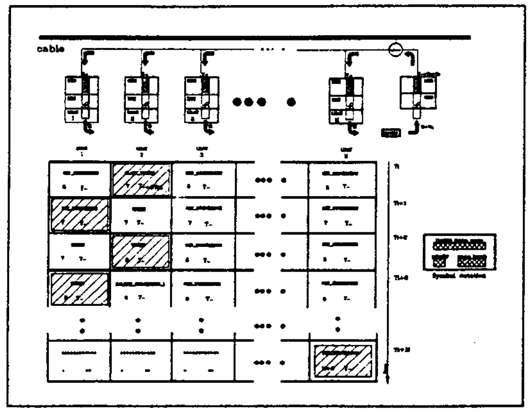

Figure 8. The drama of worst case in DMMAP.

$$S_i \le P_{ik} \cdot M\left[\frac{TRT_{max}}{N} - (M-1)T_2 - T_1 - 7T_{sl}\right] \qquad (8)$$

To compare the service time of DMMAP versus the channel number, we assume the station number in the network N is a constant.

1. Let the Si equals to zero for calculating the intersection of the service time and the number of LMAC in a station. From equation (8), we obtain:

$$M = \frac{\frac{TRT_{max}}{N} + A - 7T_{sl}}{T_2} = M_x \quad \text{or} \quad M = 0$$

2. In single channel case, M = 1, and substitute it into equation (8) to calculate the service time of DMMAP, it is less than the service time of IEEE 802.4 since the response window of former is larger than latter's.

$$S_i = P_{ik}\left(\frac{TRT_{max}}{N} - T_1 - 7T_{sl}\right) = S_1 \qquad (\text{DMMAP}_1) \qquad (8\text{-}1)$$

$$\le \frac{TRT_{max}}{N} - T_{sl} \qquad (\text{IEEE 802.4}) \qquad (8\text{-}2)$$

3. In order to calculate the number of LMAC and its service time at the maximum service of DMMAP, let $\frac{d}{dM} S_i = 0$.

$$P_{ik}[(\frac{TRT_{max}}{N} - T_1 - 7T_{sl}) - (2M-1)T_2] = 0$$

$$\therefore M = \frac{\frac{TRT_{max}}{N} + A - 7T_{sl}}{2T_2} = \frac{Mx}{2} \qquad (9)$$

Let $X = \frac{TRT_{max}}{N} + A - 7T_{sl}$, so the equation (9) become to

$M = \frac{X}{2 \cdot T_2}$, then substitute the result into equation (8) to calculate the maximim service time :

$$S_i = P_{ik} \cdot M \cdot (X - M \cdot T_2) = P_{ik} \cdot \frac{X}{2T_2} \cdot (X - \frac{X}{2T_2} \cdot T_2)$$

$$= P_{ik}\frac{X^2}{4T_2} = \frac{P_{ik} \cdot (\frac{TRT_{max}}{N} + A - 7T_{sl})^2}{4T_2} \qquad (10)$$

In the figure 9, we draw the plot using above equations, and we found the extended bandwidth is is a parabola curve versus channel number. The cause of this phenomenon is the overhead of response window will be square growth with channel number increment. The slope of service time curve will be flatter when the number of channel approach to a half of Mx, that is few benefit for increasing channel number at that time. If the increasing number continuously grows, then the service time will reduce to zero at the channel number Mx. In that time, all bandwidth of network is consumed by transmitting MAC frames, and no data frame can be transmitted. However this phenomenon is impossible to happen in DMMAP, since we find the channel number at the top of curve is a very great number, it makes the linear growth of service time in range of lower channel number.

The Gain of service time of DMMAP is a benefit measure that divides the service time of DMMAP as equation (8) to the service time of IEEE 802.4 as shown in (8-2).

$$\text{Gain} = \frac{\text{Service time of DMMAP}}{\text{Service time of IEEE802.4}}$$

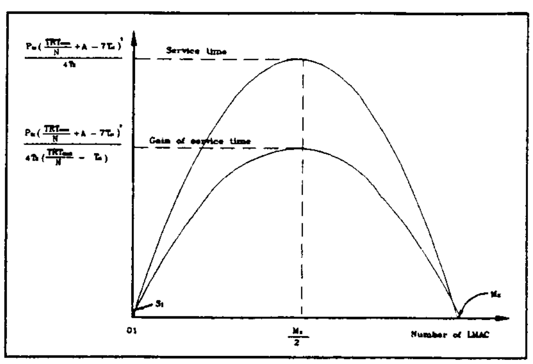

Figure 9. Comparison of the service time and gain versus the various LMAC number.

$$\leq \frac{P_{ik} \cdot M \cdot (\frac{TRT_{max}}{N} + A - 7T_{sl} - MT_2)}{\frac{TRT_{max}}{N} - T_{sl}}$$

$$= \frac{P_{ik} \cdot T_2}{\frac{TRT_{max}}{N} - T_{sl}} \cdot M^2 - \frac{P_{ik} \cdot (\frac{TRT_{max}}{N} - 7T_{sl} + A)}{\frac{TRT_{max}}{N} - T_{sl}} \cdot M$$

$$= \alpha \cdot M^2 - \beta \cdot M$$

1. Let Gain = 0 $\quad M = \frac{\frac{TRT_{max}}{N} - 7T_{sl} + A}{T_2} = M_x$

or $\quad M = 0.$

2. Let Gain = 1

$$M = \frac{\beta + \sqrt{\beta^2 - 4\alpha}}{2\alpha} \text{ or } M = \frac{\beta - \sqrt{\beta^2 - 4\alpha}}{2\alpha}$$

3. Let $\frac{d}{dM}\text{Gain} = 0 \quad M = \frac{\frac{TRT_{max}}{N} + A - 7T_{sl}}{2T_2} = \frac{M_x}{2}$

$$\text{Gain} = \frac{P_{ik}\frac{X^2}{4T_2}}{\frac{TRT_{max}}{N} - T_{sl}} = \frac{P_{ik} \cdot (\frac{TRT_{max}}{N} + A - 7T_{sl})^2}{4T_2 \cdot (\frac{TRT_{max}}{N} - T_{sl})}$$

Conclusions

The high speed LAN DMMAP adopts the traditional network configuration of IEEE 802.4, and its protocol is compatible with the existent protocol of IEEE 802.4. The architecture of network interface of station on the DMMAP is adjusted by expanding the receiver, LMAC, and transmitter. Since the DMMAP adopts only two transmitters that saves the cost of production and electric power usage, though it needs paying a little of contention overhead of transmitting MAC frame. In above derivation, we reserve the benefit of dynamic assignment mechanism, and treat the analysis to a weak condition that frequently happen some problem, so we assert the network architecture should be a practical network.

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