

THE ELEMENT OF ARRAY ANTENNA EFFECT TO NETWORK BASED ON IEEE 802.11 DCF

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Abstract

All aspects of humans connect to devices and applications on wireless networks, such as connecting to computers for online study during the COVID-19 pandemic, connecting to tablets to watch movies, and connecting to mobile phones for financial transactions. These factors have driven the development of higher-performance wireless networks. However, the number of nodes is increasing rapidly. Therefore, the network cannot support all nodes as they use channels simultaneously. Moreover, the bandwidth of wireless networks is limited to a maximum value. So it is a good idea to optimize the wireless network at the lower layer. In the physical layer, the array antennas use to transmit and receive data. The beamforming of the array antenna can form a beam at all angles and connect the nodes from the source. This antenna uses the placement of the antenna elements to create the array pattern. Therefore, this is important for array patterns. In this paper, we analyze the impact of antenna elements on wireless networks based on 802.11 DCF. The indicators are communication links, throughput, and delay.

Keywords: Network, Antenna

Introduction

So far, the development of wireless networks has elevated a better human life in many parts: speed, frequency, the capacity of data, and new technologies. However, the wireless network is still using an antenna in the transmitter and receiver. The popular hardware is an array antenna because of flexibility and responsiveness in the direction around the transmitter. Array antennas can give specific beams to the users in the area. In addition, they can reduce noise and increase signal strength. Therefore, this type of antenna is suitable for wireless networks.

Array antennas classify into three types according to the arrangement of their elements. The first type is a linear array. This design consists of more than one element and arranges them in a single line, $1 \times N$ or $N \times 1$, where N is the number of the antenna element. Therefore, a linear array is a favorite for a simple arrangement and a high gain beam direction. However, the limitation of this type is the beam-direction that cannot form at all angles. Chi *et al.* (2020) present the linear arrays for IoT applications operating in LTE and 5G bands with an intermediate gain. Besides, Sreelakshmi *et al.*

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(2018) use in the vehicular application. The second type is a planar array which consists of elements arranged in two different axes. The antenna element uses variables N and M as $M \times N$ or $N \times M$. This arrangement has the advantage of beamforming in any direction. However, the hardware contains many phase shifters to control each element. So, the cost is high. Garcia-Marin *et al.* (2019) present the planar array antenna on a microstrip operating in KU Band. The third type is frequency scanning array. This use a circuit in a transmitter to control beamforming. This type of antenna is susceptible to interference and has low bandwidth.

The concept of array antenna is similar to the directional antenna providing beamforming in a specific direction. The array pattern determines the distance that the nodes can communicate. So, this is important in the choice of application. In antenna array design, Kelley and Stutzman (1993) proposed the antenna design which coupling effects to avoid unnecessary interference. Also, the acceptable distance of each element is 0.5λ or less. The authors of Inthanil and Uthansakul (2019) examined the effect of the Front to Back (F/B) ratio on the network as the high F/B rate antenna has a significant positive ascendant on the wireless networks. It is well known that antenna arrays have gain that varies with the number of elements. The relationship between F/B and the antenna gain is simple to explain. When F/B is high, the antenna gain at the target angle is high too, but it is true in every case. In addition, the increase in F/B is not limited to the placement of elements. The research that studies the increase in F/B is Dahri *et al.* (2019); Huang and Bu (2021).

Much of the research focuses on improving the shape of the antenna array. There are many forms to support wireless networks, such as Al Abbas *et al.* (2019); Chung *et al.* (2019); Parchin *et al.* (2019); Ren *et al.* (2019). The type of improvement includes the enlarged port for connexion to the elements in Chattha *et al.* (2019); Abdelgwad and Ali (2020) the small size for lower cost and easy installation in Boologam *et al.* (2020); Sampath and Selvan (2020) Feturemore, the stupendous thing about the extension is the antenna element. Many research papers use a different number of elements. They focus on other aspects like frequency, radiation pattern, and gain. They have also been measured based on the antenna factor. However, in previous research work, different elements have changed the antenna factor. Therefore, we propose to focus on the number of antenna elements because the research considers, for example, the small size, many feed ports, and many shapes. So, the above study can use.

Nowadays, wireless network applications are becoming more and more diverse. The number of devices referred to as nodes are increasing. Besides, during high traffic loads, nodes in the same region compete for access to the channel. Usually, for nodes in a wireless network, there is a sort of pre- and post-transmission. However, the latency effect and data collisions are continuous occurred. In the research of Szymanski (2014) Attempts to reduce network latency and delay in Gao *et al.* (2008) designed a delay control system for the wireless network. So, the problem of the wireless network continues to occur. Based on past research surveys, the research attempts to solve this problem, the best solution is to minimize the impact of latency and delay as much as possible. So, therefore, this paper mainly focuses on improving wireless network that to mitigate this problem.

Most of the research topics are trying to improve the wireless network, such as improving the medium access control (MAC) protocol to transmission process to allocate data speed and improving the physical layer addressing antennas for example, to increase the antenna gain in Sehrai *et al.* (2020) to Making the coverage area larger in Prinsloo *et al.* (2019) and to reduce device size in Nabil and Faisal (2021) Therefore, the consideration of two layers is proposed in the model. In the physical layer, the effect of antenna element proliferation is proposed. In the MAC layer, the factors of comparing in the wireless network are throughput and delay factors.

In this paper, we study the effect of antenna array elements on the wireless network. We divide the simulation into three parts as shown in Figure 1. The purpose of the analysis in antenna pattern test the change in radiated pattern with concept of increasing element. In the topic communication link, the purpose test the capability of node in the wireless network. The throughput and delay topic confirms the element's impact on the wireless network. This article presents several different elements. It is well known that an increase in the number of elements increases the gain. In addition, this article presents guidelines for building an antenna for higher network efficiency.

Methods

The objectives of this article include:

- We analyze the increasing element that affects an array pattern, communication link, throughput and delay.
- We optimize the wireless network with an array antenna.

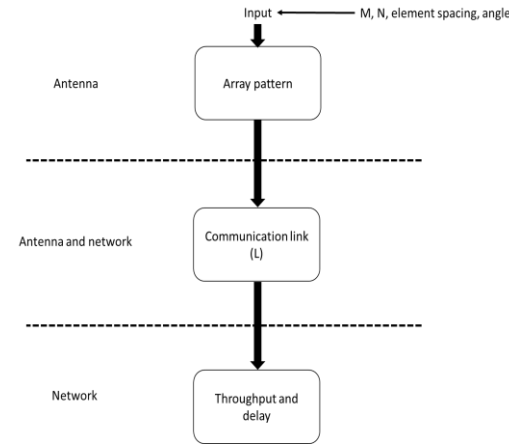


Figure 1. Mechanism design

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- We explain the essential parameter for an antenna that design to work on the wireless network.

The array antennas are specific hardware for communication. In the Physical (PHY) layer, the communication begins when the receiver receives signal. Moreover, this level is higher more than the signal threshold. This process splits the desired signal out from the interference signal. On the other hand, the medium access control (MAC) layer base on the mechanism of 802.11 DCF. The tradeoff data between transmitter and receiver uses frame to confirm the communication. The procedure is Request to Send (RTS), Clear to Send (CTS), DATA, and ACK frame. This method is used to decrease the hidden node problem from Rahman and Gburzynski (2006) and the deafness problem from Choudhury and Vaidya (2004). In general, the omnidirectional mode uses to send CTS and receive the RTS. The directional mode use for DATA/ACK. Therefore, this paper assumes that node can operate in two modes. The next section is theory of array patten for simmulation. There is contain of receive signal, and weighting.

A: Array pattern

The network operator wants to monitor network performance all the time because it optimizes their network. However, we can't verify the performance of every user. So, there is research modeling it to measure its quality. The authors of Tang *et al.* (2018) created a model for a Wi-Fi network. The simulation measures the throughput and delay of the network. In the model, they use the users as the parameter. So, that model can analyze the network performance.

In this article, the nodes are random in a circular area. The network contains radius (R) and area (πR^2). All nodes in the network are the same communication distance and the same transmission power. Moreover, each node installs a planar array antenna. The number of elements is equal to $M \times N$. The distance between elements is 0.25λ . The desired angle is 45 degrees and the frequency is 2.45 GHz. The situation of the model starts with one receiver and transmitter. When the communication begins, the signal comes from the transmitter. So, the $M \times N$ -element of the receiver builds the antenna pattern to support the desired signal. To simplify the concept, we explain the array pattern in Figure 2 and Equation (1).

$$\text{Pattern} = \sum_{m=1}^M \sum_{n=1}^N w_{m,n} \times x_{m,n} \quad (1)$$

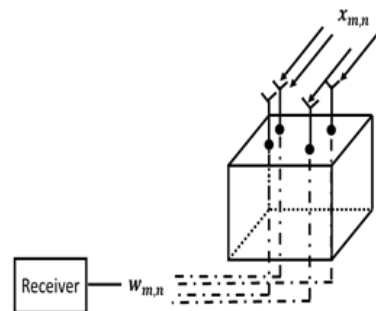


Figure 2. Array system

The array pattern in equation 1 contains the coming signal (x) and weighting (w) from each element. The array factor is the position function. The position of the element receives the difference

signal level and time. Therefore, the signal in each element should be weighted for the combined signal. Moreover, the array pattern varies from the array factor. So, the array factor builds in this method. When the element $M=N=2,3\dots10$.

B: Communication Link

The antenna is used to communicate between nodes each time. The type of display affects the network performance with the difference. The work presented in Babich and Comisso (2009) compared each type of antenna and proposed the network model in a circular network with radius R . Their model proposed the array antenna with the best type. The reason is that array antennas decrease their side lobes and force beam to protect the interference.

For the model conditions, the communication link at the same time (L) includes the active node and inactive node. The active node means that the device is still online although there is no communication and the inactive node is that the device is offline. The number of nodes that request access to the channel at the same time is equal to L . Signal to noise ratio threshold ($SINR_t$) classifies the parameter L . This method splits the desired signal from the interference signal. This classification considers the coverage area. Therefore, the array pattern is included in this process. So, the communication link simultaneously describes as Equation (2).

$$L = \frac{2^\alpha G^2 - 1}{2 SINR_t R^2 R_s^{\alpha-2} (M_1 G_1 B_1 + M_2 G_2 B_2)} \quad (2)$$

where M_1 , M_2 , B_1 , and B_2 is

$$M_1 = R_s^{1-\alpha} - R^{1-\alpha} / [2\pi(\alpha - 1)R] \quad (3)$$

$$M_2 = R_s^{1-\alpha} / [2\pi(\alpha - 1)R] \quad (4)$$

$$B_1 = \int_0^{2\pi} G_F(\theta) \theta d\theta \quad (5)$$

$$B_2 = \int_{\frac{\theta_{3dB}}{2}}^{2\pi - \frac{\theta_{3dB}}{2}} [G_2 G_F(\theta)]^{\frac{1-\alpha}{\alpha}} - 1 \theta d\theta \quad (6)$$

Where the maximum distance of array pattern is R_s , the path-loss exponent is α ($\alpha = 4$), the antenna gain is G and the average gain is G_1 . This average obtains in radius from zero to 2π . The average outside gain is G_2 . This average obtains in radius $\frac{\theta_{3dB}}{2}$ to $2\pi - \frac{\theta_{3dB}}{2}$. The general gain function is $G_F(\theta)$. The Half power beamwidth angle is θ_{3dB} , and the general angle is θ .

The communication link is not the indicator of the speed and delay of network performance. However, this contains the network capacity. This

variable shows the potential in the PHY layer. In the next section, we will cover network performance with Throughput and Delay. There are key factors to indicate network performance.

C: Network Analysis

The behavior of nodes is defined as follows in Figure 3. The sending node is node S, and the receiving node is Node D. Wait time for Node S until the Distributed coordination function (DCF) Inter-frame Space ends. Then, for the reserve channel, node S transmits RTS to node D. When node D receives the RTS, it evaluates whether it is idle or busy. Short Inter-frame Spacing is waiting time in the RTS and CTS. In an idle state, node D transmits CTS to other nodes, including node S. This step informs another node that the busy channel is active. node S receives the CTS and transfers DATA to node D before waiting for an ACK. This process marks the end of a single transmission. However, in the busy channel case, node S queue for transmitting DATA after post data finish. This is perfect communication but the real channel has the disturbance factor. This communication is possible to be wrong DATA. So, the retransmission process begins in this case. The number and time of retransmission count from the time slot (τ) and maximum contain windows size (w_0). The work presented in Murad and Eltawil (2020) showed that the probability of time slot based on IEEE 802.11 DCF, when analyzed from a similar model, can be obtained from Equation (7).

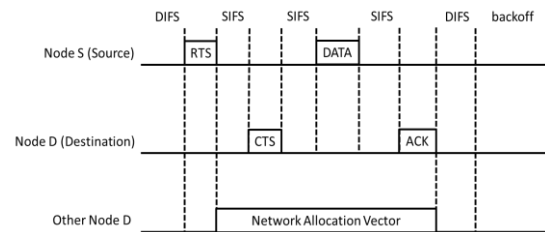


Figure 3. DCF Algorithm

$$\tau = \frac{2(1-2p)}{w_0(1-2p) + p((W-1) + (2p)^m)} \quad (7)$$

Where p is the probability for sending.

The Markov chain model expresses and the probability of sending data at least once as is presented by p_{tr} . The probability of sending wrong data as is p_c . The probability of sending data successfully is p_s . So, we can express as Equations (8) to (10).

$$p_{tr} = \binom{n}{1}(1 - (1 - \tau)^n) \quad (8)$$

$$p_s = \frac{\sum_{j=1}^L \binom{n}{j} \tau^j (1 - \tau)^{n-j}}{p_{tr}} \quad (9)$$

$$p_c = \frac{\sum_{j=L+1}^n \binom{n}{j} \tau^j (1 - \tau)^{n-j}}{p_{tr}} \quad (10)$$

Where n is the number of all node in networks which contain active node and inactive node ($n \geq 2L$). The model uses a communication link to find the probability of transmission. So, the throughput is expressed as Equation (11) and delay as Equation (12).

$$T_{hu} = \frac{p_{tr} p_s (\text{Packet}) (\text{Data rate})}{(1 - p_{tr}) \sigma + p_{tr} p_s T_{si} + p_{tr} p_c T_{ci}} \quad (11)$$

$$\text{Delay} = p_{tr} p_c \times \frac{\left(\frac{1}{p_{tr}} - 1\right) \sigma + p_s T_s + p_c T_c}{\text{Packet}} \quad (12)$$

$$T_{si} = \text{MACH} + \text{PHYH} + \text{SIFS} + \text{ACK} + \text{DIFS} + 2\sigma \quad (13)$$

$$T_{si} = \text{MACH} + \text{PHYH} + \text{SIFS} + \sigma \quad (14)$$

The final step of the network assessment is comparing Throughput and Delay against the number of nodes in the network.

Results and Discussion

A normalized array pattern simulation includes the element M and N from 2 to 10. The result from the array pattern section is shown in Figure 4. The basic step starts from a linear array antenna. In the PHY layer, the arrangement of an element has one column. Figure 4(a) to Figure 4(f) show the strength of the front lobe when increases the element and Figures 4(g) to 4(i) show the strength of the back lobe. This trend showed the many elements build undesired beams to interfere with another node. The simulation set the angle to 45 degrees. However, the linear array antenna cannot fully operate and form the beam to desired. Therefore, we simulate the planar array to the flexibility of the network. The correlation of the number of elements affects the

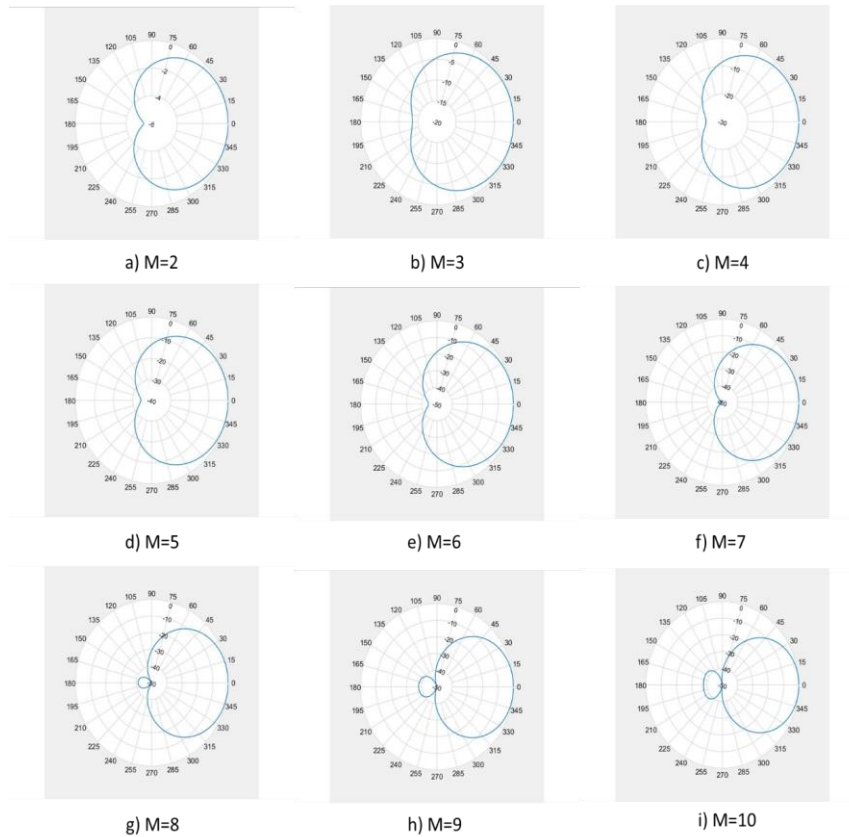


Figure 4. Linear array antenna with M elements

network capacity. It expands network capacity at the saturation points. Figures 5(a) to 5(d) show the beam that is directed at a 45-degree angle and the back lobe is reduced in size. The reason is the power from the surrounding area forming in the desired direction. So the gain in that direction is increased accordingly. However, in Figures 5(e) to 5(i), the beam deflects out from a specific 45degrees. Moreover, the null begin at some area. This can interfere with other nodes and cannot receive the signal in some directions. The communication link values are shown in Table 1 when we use the same environmental conditions of Babich and Comisso (2009). Comparing the trends of Figure 5(a) and above, the number of L is higher than Figures 5(e) to 5(f) There is a change in the radiation pattern, with the sidelobe and back lobe being very large until L is saturated. So, the available F/B is the

highest value as well. Comparing Figures 5(g) to 5(i), the back lobe and side lobe are greatly enlarged, causing the F/B that should have been increased, resulting in a decrease in L size accordingly. From

Table 2. Variable for simulation

Variable	Value
Packet	8184 bits
PHY header (PHYH)	128 bits
MAC header (MACH)	272 bits
ACK	240 bits
Datarate	54 Mbps
Propagation delay (σ)	1 μ s
Maximum number of retransmission (m)	5
Maximums contain windows size (W_0)	16
DIFS	34 μ s
SIFS	16 μ s
SINR _t	10 dB

Table 1. The communication links

M×N	2×2	3×3	4×4	5×5	6×6	7×7	8×8	9×9	10×10
Link	4	5	7	8	9	10	9	9	8

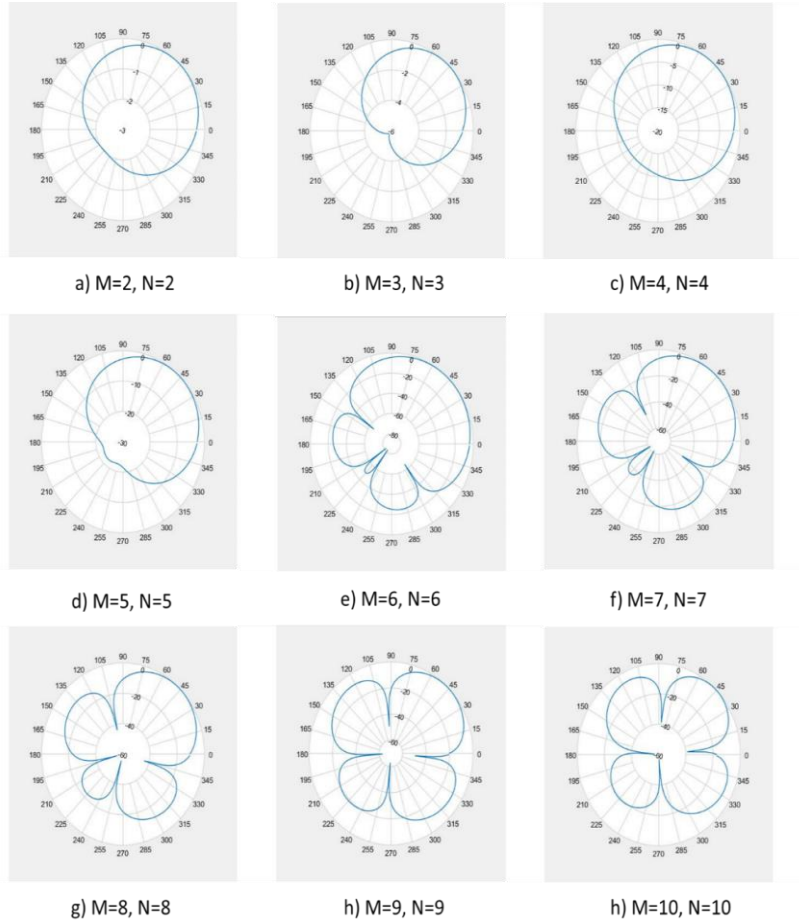


Figure 5. Array pattern of M×N element

thesimulation results, the number of elements in the network froc Figures 6 shows that the saturation throughput of adding an element positively affects the number of nodes entering the same period with saturation points at $M=7$ and $N=7$. Furthermore, the network delay in Figure 7 shows that adding elements can reduce the delay which is good for the network. However, as the number of nodes increases, the increase or decrease in the number of elements no longer affects. The number of elements contributes to network performance. From the network operator's point of view, the number of nodes accessing the network is important. For networks with no more than 40 access nodes, operators do not need the best antenna performance

to choose the number of elements $N=7$ and $M=7$ to save the phase-shifting cost. Therefore, this study provides great flexibility to network operators in their choice. For the network designer, comparing the four parameters of the antenna pattern, communication link, throughput and delay showed that changing the number of elements increases the gain and the F/B. In fact, the results show that changing the radiation pattern is the cause to increase the number of elements initially gives the best throughput until the sidelobe and side lobe are so large that they interfere with other nodes in the network. So the network design, antenna design, and gain alone are not enough to be considered. The radiation pattern should also be related to the model

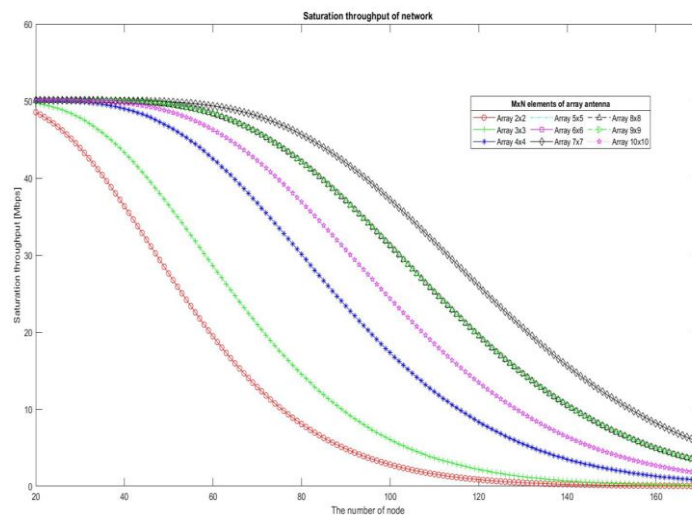


Figure 6. The saturation throughput of network

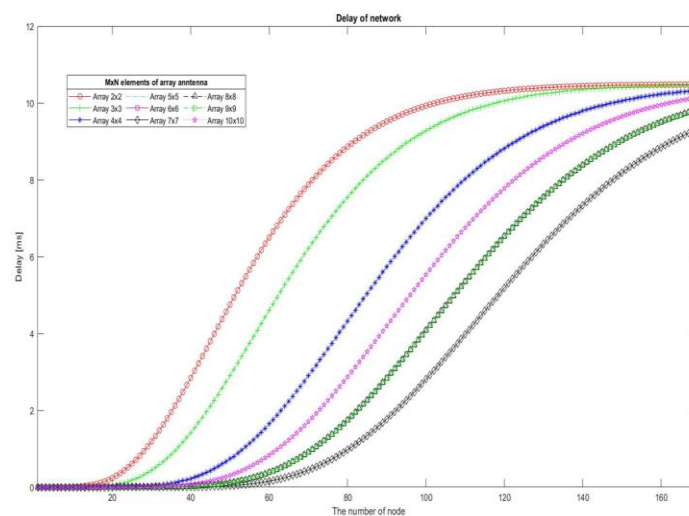


Figure 7. The delay of network

Conclusions

The array antenna is the hardware for transmission. The improved antenna depends on the antenna parameter. The popular parameters are gain and operation band. Furthermore, the wireless network system still uses an array of antennas. Therefore, the analysis of the antenna effect is proposed in this paper. The wireless network respects the 802.11 DCF. There are contain the protocol to control the data. Moreover, some mechanisms are related to the PHY layer. The analysis considerate the antenna pattern shape. So, interference from the source node is proposed. The prototype is a linear array. There shown the F/B and back lobe effect. This effect increases in different numbers of elements. When the element is saturated, the back lobe will appear. The planar array section is used to replace the linear array because of the angle desired. The planar array showed the increased element is increasing the communication link. However, the condition is undersaturation. The network parameter shows the performance of each element to support the number of the node. So, Throughput and Delay support the maximum element for $M=7$ and $N=7$. The antenna pattern exhibits saturation. A stronger element than saturation does more harm than good. We have proposed to consider the importance of antenna design in the network. The effect is to emphasize the radiated power pattern and F/B ratio to increase the efficiency of the network. F/B ratio to increase the efficiency of the network.

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