A Schedule based MAC in Wireless Ad-Hoc Network by Utilizing Fuzzy TOPSIS

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Summary
Wireless ad-hoc networks are known as a decentralized type of wireless networks that have no pre-existing infrastructure. In this network, data transmission has done by intermediate nodes as a multi-hop. Ad-hoc network suffers from some restrictions such as limited resources on bandwidth, battery storage and etc., therefore, appropriate protocol design is main challenge in them. The Medium Access Control (MAC) protocols are responsible for coordinating the access to the shared medium and have significant importance since the wireless communication channel is inherently prone to errors and unique problems. A lot of research has been conducted on MAC protocols, however, Time Division Multiple Access (TDMA) based approaches attract researchers in this area, because they have properties such as prevent of collisions, fair bandwidth sharing and etc. In this paper, we propose an optimization model for time-resource allocation in wireless ad-hoc networks. Then, the main criteria, power consumption and delay, are formulated, next, we take the advantages of the fuzzy TOPSIS to assign more appropriate time-slot to nodes. Simulation results show that the proposed multi criteria algorithm is more efficient than available approaches.
Keywords:
Ad-hoc network, time allocation, TDMA scheduling, Multi-criteria decision making method, Fuzzy TOPSIS.

1. Introduction

A wireless ad-hoc network known as a decentralized type of network and unlike wired network, there is no managed and infrastructure to control sending and receiving data. These networks consist set of distributed nodes which communication is using by radio transmissions and establish a temporary network without supporting central management [1]. In common wireless networks, if nodes are within the transmission radio range, then direct communication between them is possible; while some nodes located at farther away, they are unable to communicate directly. Therefore, multi-hop routing in such networks has been utilized [2].
Wireless ad-hoc network employ air as a shared channel or medium to communicate between nodes. A wireless communication channel is a resource that should be shared between all members of the network. Therefore, the sharing process requires a proposal that meets the parameters considered in the network. Communication medium can be used in various aspects such as time, frequency and coding [3]. In wireless ad-hoc networks, all nodes would not be able to access the shared channel simultaneously. To solve the collision problem, providing network efficiency, avoidance of interfering and fading in the channel and rising up the link quality, Medium Access Control protocols (MAC) are needed. The key purpose of access control protocol is to make available Quality of Service and high efficiency for bandwidth as well as saving power consumption. Therefore, MAC protocols tend to develop an exclusive strategy to resource allocation. MAC protocols are classified into contention-based and schedule-based protocols. In contention-based protocols, a given transmit chance toward a destination can originally be taken by each adjacent node. Due to randomly and access chance, hidden-terminal situations, collision, wasting energy for both transmitter and receiver, idle listening as well as overhearing can happen. However, transmission schedules can be computed, such that no collisions occur at receivers and hence no superior mechanisms are needed to avoid hidden-terminal conditions. In schedule based algorithms, the time-slots for each node are determined, but, this protocols need to be synchronized, that means send and receive time of node must be synch [4].

According to importance of MAC in wireless ad-hoc networks, the aim of this research is to introduce a schedule-based MAC protocol based. At first, we model time allocating problem as an optimization model that can compute send and receive time of nodes. Then, due to the high time complexity of solving the mathematical model, we present an algorithm based on Multi Attribute Decision Making (MCDM) and fuzzy TOPSIS. The proposed algorithm in terms of time complexity has better performance in networks that faces with more mobility and topology changes.

The remainder of this paper is organized as follows: Section 2 reviews background information and the works related to our design. Section 3 describes the system model,

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the optimization problem for the TDMA-based scheduling and parameter definition. Section 4 provides some simulation results and analysis. Finally, Section 5 summarizes the conclusions and our results.

2. Background and related work

The overall performance of ad-hoc networks depends on energy efficiency, hence, it can be the most important factor in the design networks access control protocol [5]. These networks suffer from some limitations such as battery power, communication bandwidth, computing power and memory [6]. There are many challenges in ad-hoc network design, including resource allocation and access control to the shared channel. MAC protocols control access to shared medium that have many effects on energy consumption and delay [7].

The shared media and multi-hop structure in data transmission of ad-hoc networks cause to propose numerous MAC protocol to eliminate potential collision and interference and design of MAC protocols. In TDMA based approach, the transmission resource is divided into time-slots. In particular, one or more time-slots may be allocated to a node [8]. In other words, TDMA scheduling approaches form time-slots with a same and fixed period, which each node performs transmission at least in one time-slot. In this scheduling, each frame is divided into multiple time-slot that can be allocated to different nodes or links and existing bandwidth for limited and alternative time periods is accessible for users [8]. In order to prevent collision in a time-slot, adjacent nodes to a node that is sending are not allowed to transmit data packets. To determine the total interference on outgoing links of sending node, defining a specified threshold is needed that the amount of accumulated interference is measured by this threshold and does not exceed.

In [9], authors proposed a adoptive model, with AHP-TOPSIS, to evaluate the efficiency of two DSR and DSDV routing protocols, which the system is enable to switch to optimal protocols. Their method is a combination of AHP and TOPSIS that choose the optimal protocol. In [10], advantage of contention based and time division protocols to establish an advertisement-based TDMA is combined, that is a distributed TDMA based MAC protocol for wireless sensor networks. In [11], two MAC protocols are proposed that one is distributed and the other is cluster-based. By using advantages of Fuzzy TOPSIS in [12], to select the energy-efficient network in heterogeneous wireless networks, a method has been presented. The proposed fuzzy TOPSIS-based algorithm takes into account some factors such as user preferences, network situations, QoS and energy consumption requirements, in order to make decision the optimal network and reaches the best balance between performance and energy consumption in wireless networks. Khalily-Dermany in [13] made a theoretical determination of the achievable maximum multicast information flow after diverse topology control mechanisms. In [14], authors used a multi-criteria decision-making method for selecting cluster head with regard to the four criteria: the residual energy, the number of neighbors, the distance below the base station and the transmission range for each node. Karkooki et al. in [15], with the goal of reducing energy consumption and extending lifetime, formalize the network lifetime as an optimization programming.

In [16], due to the time division scheduling and by using contention window, an algorithm has been raised in order to control the medium access in wireless networks. Also related to this type of programming in [17], an energy efficient structure is proposed in order to combine link scheduling and routing in multi-hop TDMA based wireless networks. In [18], a dynamic TDMA based MAC protocol designed to suggest collision-free transmissions to provide QoS in ad-hoc networks. In [19], a TDMA based routing protocol for Multi-hop wireless vehicular ad-hoc networks is presented, which providing the capability to transmit or receive packets over long distances (multi-hops) is considered. In [20], a new self-sorting MAC protocol is presented for high-density scenarios which, allows nodes to sort with others in a collision tolerance method before transmitting data. In [21], a QoS scheme for ad-hoc networks by merging TDMA scheduling and IEEE 802.11 DCF. In their proposed pattern, the channel time is composed of two different periods, specifically TDMA and DCF periods.

3. Background and related work

In this section, first we describe our network model, then the time-slots allocation in a scheduling is modeled as an optimization problem.

We model an ad-hoc network with a directed graph $G(N,A)$ which includes a set of N nodes and each node represents $i \in N$ a radio unit in the network, also a directional communication link is expressed by the set of edges A. Accordingly, wireless medium is error-prone and to establish a direct communication link (i,j) between two nodes i and j, amount of noise and interference on the network should be considered.

Let $L_b(i,j)$ denotes the loss-rate between pair nodes i and j. The threshold γ_0 determine existance of a direct communication link between two nodes i and j according to the signal to noise ratio of the link. More precisely, it is proved a link (i,j) can be utilized if,

$$SNR(i,j) = \frac{P_i}{L_b(i,j)N_r} \geq \gamma_0 \quad (1)$$

where P_i denotes the transmitting power of i and N_r denotes the effect of thermal noise. In addition, in order to be error-free the created link between mentioned two nodes, Signal to Interference Ratio (SNR) is important and it considered by γ_1 threshold. To establish direct and error-free links, the following equations is considered [22]:

$$SIR(i,j) = \frac{P_i}{L_b(i,j)\,(N_r + \sum_{k\in N, k\neq i,j} \frac{P_k}{L_b(k,j)}} \geq \gamma_1 \quad (2)$$

In addition, two nodes that have a direct link to the third node should have different time-slots. Finally, a time-slot can be assigned to a node that only if for all outgoing links of the node, has a reasonable amount of SIR. Generally, restrictions for the time-slot assignment to network nodes, summarized as follows:

- Two adjacent nodes that are connected by a link should be assigned dissimilar time-slots.
- Two nodes that have a direct link to the third node should have different time-slots.
- Only if all the outgoing links of the node satisfy mentioned SIR constraints, a time-slot can be assigned to a node for transmitting data.

The main purpose of the time-slot assignment problem is to assign at least one time-slot to each node, such that the minimized total number of time-slots is reached. Let the set $T = \{1, \ldots, |T|\}$ denotes a set of time-slots. We introduce to varibles x_{it} and y_t, in which, if time-slot t is assigned to node i then $x_{it} = 1$ and otherwise $x_{it} = 0$ (time-slot is not assigned to node). Also, if time-slot t is used by at least one node then variable $y_t = 1$ and otherwise $y_t = 0$ (time-slot is not used by nodes). According to [22] that was improved in [23], time-slot allocation problem offers into a minimization model is defined as follows:

$$min \sum_{t\in T} y_t \quad (3)$$

$$\sum_{t\in T} x_{it} \geq 1, \forall i \in N \quad (4)$$

$$x_{it} \leq y_t, \forall i \in N, \forall t \in T \quad (5)$$

$$x_{it} + \sum_{j:(i,j)\in A} x_{jt} \leq 1, \forall i \in A, \forall t \in T \quad (6)$$

$$\frac{P_i/N_r}{L_b(i,j)} \geq \gamma_1 \,(1 + \sum_{k\in N:K\neq j,j} \frac{P_k/N_r}{L_b(i,j)} x_{kt}) \quad (7)$$

$$x_{it} \in \{0,1\}, y_t \in \{0,1\}, \forall i \in A, \forall t \in T \quad (8)$$

The objective function (3) minimizes the total number of time-slots which are assigned to nodes. Constraint (4) ensures that all nodes are assigned at least one time-slot; in constraint (5) it is considered that time-slot t which is assigned to node i, not assigned to other node simultaneously. Constraint (6) ensures if two nodes are connected or they have other links to a third node then different time-slots should be had, in other words, time-slot t only assigned to node i or one of its neighboring node. SNR and SIR constraints are defined in (7) that is related to establish direct and error free link between tow nodes. For more details see [22] and [23].

The optimization model try to assign time-slots to the nodes, but, it never consider other issue that have important effect on wireless networks. The key purpose was that assigns at least one time-slot to each node, so, the total number of time-slots are minimized. We employ two main criteria including end to end delay and energy consumption in proposed approach, which described in next section.

Power supply is critical and valuable for wireless nodes because nodes have limited and a few battery capacity and also recharging or earning energy from environment is complex and volatile. Therefore, energy consumption in the network must be controlled carefully. Energy consumption is related to send and receive data packets in ad-hoc network. Energy requirement to transmit data packets, E_{tx}, with K bit, under distance d between source and destination is formulated as follows.

$$E_{tx} = k * E_{elec} + k * \varepsilon_{fs} * d^2 \; if \; d \leq d_0 \quad (9)$$

$$E_{tx} = k * E_{elec} + k * \varepsilon_{mp} * d^4 \; if \; d \geq d_0 \quad (10)$$

where E_{elec} represents the wasted energy per bit to run internal transmitter or receiver circuits, variables ε_{fs} and ε_{mp} are energy consumption value in amplifier which is rely on amplifier model and $d_0 = \sqrt{\frac{\varepsilon_{fs}}{\cdot}}$. Energy consumption of reception is formulated as $E_{rx} = k * E_{elec}$.

On the other hand, task of each MAC protocol is to set nodes access to share media such that the performance requirements for specific application are met. Average time that it takes a packet to go from one point to another in the network, specifies packet delay. Generally, end to end packet delay is determined via factors such as propagation delay, queuing delay, transmission delay and processing delay which is formulated as follows:

$$D_{end-end} = N\,[d_{trans} + d_{queue} + d_{prop} + d_{proc}] \quad (11)$$

Three types of delay, queue d_{queue}, propagation d_{prop} and transmission d_{proc} delays considered as a constant value. Since in proposed model have not employed routing algorithm or queuing system and propagation delay; so queuing delay and transmission delay depend on bandwidth as well as kind of queuing, therefore we consider only waiting time to access channel. About mentioned delay in networks, transmission delay is related to packet number, data volume as well as routing type, queuing delay depends on queue length and related to data volume and for this reason that have no relation with scheduling method; according to time-slot allocation for node order to assign delay is estimated.

4. Proposed Model

Multi Criteria Decision Method (MCDM) is known as a decision making problems that are frequently encountered in practice. Choice of one alternative between available alternatives is considered and is used in order to choose best alternative between m alternatives. One of MCDM methods, fuzzy TOPSIS is based on the concept that distance of one alternative A_i from positive ideal and the negative ideal are considered. Means that selected option must have a shortest distance from the ideal solution and also has the longest distance from the negative ideal solution. With regard to the optimization problem, the main goal is that at least one time-slot assigned to each node, so that the total number of time-slots is minimal. In the proposed problem, criteria like energy and end to end delay is considered.

The first step is making decision matrix. Primarily due to the 2 criteria and m alternatives and evaluation of all alternatives for all different criteria, decision matrix is composed as follows:

$$\tilde{D} = \begin{bmatrix} \tilde{X}_{11} & \tilde{X}_{12} \\ \vdots & \vdots \\ \tilde{X}_{m1} & \tilde{X}_{m2} \end{bmatrix} \quad (12)$$

In this research, due to fuzzy scheme for fillings matrix decision all values should be fuzzy that in this fuzzy problem triangular fuzzy numbers are displayed to $\tilde{X}_{ij} = (a_{ij}, b_{ij}, c_{ij})$. The second step is to determine the criteria weighting matrix that importance of each criteria of energy and end to end delay is determined by $\tilde{W} = (\tilde{W}_1, \tilde{W}_2, \dots \dots, \tilde{W}_n)$. The third step is normalization or de-scales of fuzzy decision matrix that applied by linear scale change. If triangular fuzzy numbers to be considered, decision matrix elements for the criteria to be measured profitable by the following equation:

$$\tilde{r}_{ij} = \left(\frac{a_j^-}{\ }, \frac{a_j^-}{\ }, \frac{a_j^-}{\ }\right) a_j^- = \min a_{ij} \quad (13)$$

The criteria that are cost (energy consumption and delay) have negative impact. Accordingly the normalized decision matrix is created through the equation $\tilde{R} = [\tilde{r}_{ij}]$. The fourth step is to determine the weighted decision matrix. According to various criteria weigh, weighted fuzzy decision matrix denoted by multiplying the importance of each criteria in the matrix which is $\tilde{P} = [\tilde{p}_{ij}]$, where $\tilde{p}_{ij} = \tilde{r}_{ij} * \tilde{W}_i$.

The fifth step is to determine the positive-ideal solution and negative-ideal solution that measured by using MAX and MIN operators, positive and negative ideal solution for sets of alternatives are identified by equations $A^+ = [p_1^+, p_2^+, \dots, p_n^+]$ and $A^- = [p_1^-, p_2^-, \dots, p_n^-]$. Take into consideration, P_i^+ is the best value i and P_i^- is worth value of criteria between all the alternatives. These values are obtained from formulas

$\tilde{p}_i^+ = max\, \tilde{p}_{ij}, j \in J_1; min\, \tilde{p}_{ij}, j \in J_2;$ and $\tilde{p}_i^- = min\, \tilde{p}_{ij}, j \in J_1; max\, \tilde{p}_{ij}, j \in J_2;$.

Alternatives that are in A^+ and A^-, respectively, indicating which are quite good and quite worse. The sixth step calculates the distance of the positive and negative ideal solution. D_i^+ And D_i^- values, respectively, are weighed distance between the target alternative i and the best condition and the worth condition and obtained by using $D_i^+ = \sum_{j=1}^{n} d(\tilde{p}_{ij}, p_i^+)$ and also $D_i^- = \sum_{i=1}^{n} d(\tilde{p}_{ij}, p_i^-)$. The seventh step is to calculate similarity index. At this point the similarity index is calculated as follows:

$$C_i = \frac{D_i^-}{D_i^+ + D_i^-} \quad i = 1, 2, \dots, m \quad (14)$$

The final step is to rank the alternatives according to value of CC_i. At this stage, due to the similarity index, options are ranked.

5. Performance evaluation

In this section, we present simulation setup and results of proposed algorithm and compare outcomes. In particular, the proposed fuzzy TOPSIS algorithms is compared with DDETSA [4] and IAMQER [24]. More precisely, we consider two main obyion for our proposed approach where are called FT-R and FT. FT-R is based on Fuzzy TOPSIS and specific sequence of time-slots; but, FT algorithm is based on Fuzzy TOPSIS and is randomized. More clearly, the FT-R algorithm utilizes shortest path routing algorithm to select the best route and time-slots assigned to nodes in own order in given path. According to presented algorithm accompanied by routing algorithm, time-slots assign to sequential nodes in order of their locating in preset path that minimal delay in sending data can be achieved. In addition, second allocating method does not follow specific order to assign time-slots, in case the allocation of slots is randomly and by increasing the number of hops, end to end delay will be increased; because each nodes have to wait to send data packet only in own turn and time-slot which is assigned. The performance of the proposed algorithm is provided by utilizing MATLAB R2014b. We consider two cases for slot allocation. In the first case, we assumed network is predetermined with periodic sequence of allocating slots in a preset path and in the second case the assumed network is applied with random slots time allocation. We assume that 20 nodes are distributed randomly outspread in a fixed position. In addition, weights for criteria are considered equal to $W = (5,7,9)$. Table 1 shows our simulation parameters.

Table 1: Simulation Parameters.

Variable	***A4 Paper***	US Letter Paper
N	20	The number of node
K	120 Byte	Packet size
Tn	8	The number of slots allocable
W	(5,7,9)	Weight for criteria
T	200 ms	Duration of each Time-slot

Fig. 1 shows the energy consumption versus the number of generated packets. Clearly, with increasing the number of packet more energy consumed. Two proposed algorithms in compared with heuristic algorithm have relatively better energy consumption especially in higher packet rates, difference in energy value increased. Moreover, it shows that FT and FT-R algorithms have slight difference in energy consumption.

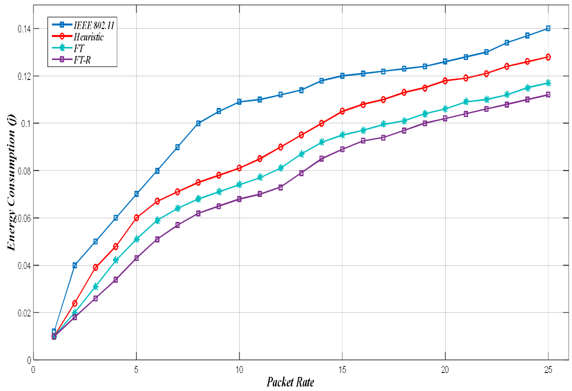

Figure.1 Energy consumption versus generated packet rates.

In next experiment, we measure energy consumption by changing the number of nodes. By increasing the number of node, energy consumption increased significantly. It is clear that proposed FT and FT-R approaches have relatively similar values is lower than IAMQER.

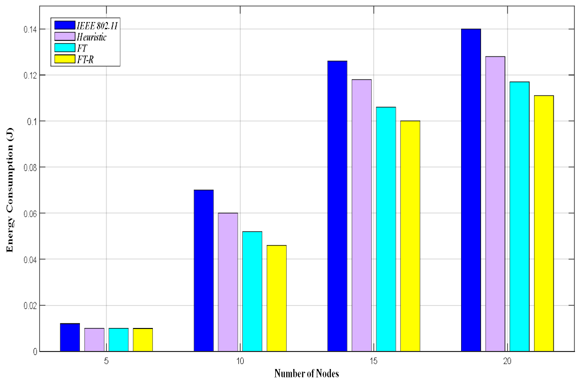

Figure.2 Energy consumption versus number of nodes.

Fig. 3 depicts end to end delay versus packet rates, clearly amount of end to end delay is raised in high packet rates and rapidly increased. Due to random time-slot allocation, FT algorithm has more delay. As waiting time to obtain the desired slot for data transmission is much higher than other algorithms. Also FT-R algorithm in comparison with heuristic methods is relatively improved.

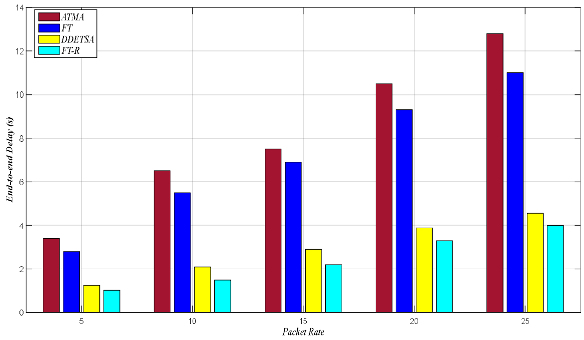

Figure.3 End to end delay versus packet rates.

In Fig. 4, the result of end to end delay versus number of nodes is depicted. Clearly, FT algorithm also has a more delay, because by increasing in the number of nodes in the network, the number of hops between nodes on the path also will be increased.

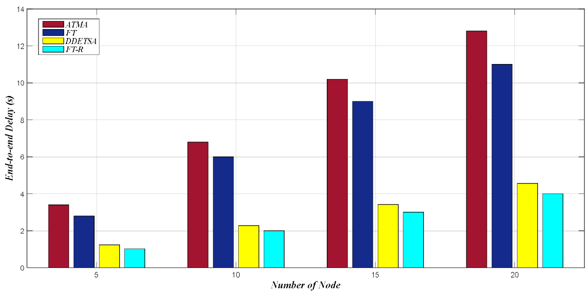

Figure.4 End to end delay versus number of nodes.

6. Conclusion and Future Works

Wireless ad-hoc networks have no pre-existing infrastructure and their data transmission has done by intermediate nodes as a multi-hop. The MAC protocols face to some complex issue such as inherently prone to errors and unique problems. TDMA based MACs has properties such as prevent of collisions, fair bandwidth sharing and etc. In this paper, we propose an optimization model for time-slot allocation. This optimization can help us to understand problem properties, but solving this problem is time consuming. Therefore, fuzzy TOPSIS approach is proposed to assign time–slot with two main criteria, power consumption and delay. The proposed algorithm performance in terms of energy consumption and end-to-end delay is evaluated. Simulation results show that the proposed multi criteria algorithm is more efficient than available approaches. According simulations, proposed approaches have relatively little difference in terms of energy consumption.

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