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Beacon Optimization for Optimized Routing Model using Tsch Network

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Abstract: TSCH (Time-Slotted Channel Hopping) protocol is introduced recently by IETF 6TiSCH working group for achieving low energy consumption and highly reliable IEEE 802.15.4e. TSCH is a synchronous MAC (Medium Access Control) protocol with IPv6 enabling Internet of Things (Io T) that are deployed in environments that are prone to interference. However, the IEEE 802.15.4e only describes TSCH link-layer design without a study of communication scheduling and network formation for high density and rapid mobile ad hoc network (MANET) which are still an open issue to the research community. The exiting model incurs high latency and energy overhead for performing device association. To address aforementioned issues, this paper present an Adaptive Routing (AR) model for MANET using mobility enabled TSCH network. Our model reduces the overhead of mobile device within mobility enabled TSCH network by introducing a novel modified beaconing for achieving Adaptive Routing design. Experiment are conducted to evaluate performance of AR over existing approaches shows significant reduction of energy overhead and attain good packet routing outcomes.

Keywords:IEEE 802.15.4e networks, Internet of Things, Mobility, Network formation, TSCH.

I. INTRODUCTION

Internet of Things (Io T) [1] has attained wide scope and adoption across various application such as human, and environment monitoring. It is used across industries for various automation purposes. In Io T environment, low power mobile ad hoc network (MANET) play a significant role in providing sensed information for automation purposes for ubiquitous communication, energy efficiency at low operational cost. To meet performance requirement of industrial applications services, several wireless standards are developed to provide reliable and efficient communication such as Wireless HART [2] and ISA100.11a [3]. In 2012, IEEE came up with a new IEEE 802.15.4e standards which extends the feature of 802.15.4 Medium Access Control (MAC). The IEEE 802.15.4e introduced Time Slotted Channel Hop- ping (TSCH) to provision multi hop communication and address interference and fading issues in wireless network. The fundamental of TSCH is a MAC design using channel hopping and time synchronization to high reliability and low power communication [4].

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The MANET device keeps on changing frequency channel at each time slot according to 802.15.4e channel hopping mechanism. As a results, impacts synchronization process among associating device and synchronizers in TSCH networks. Especially, associating device and synchronizer have to instance of time to identify the same frequency for transmitting and receiving MBs. This is because when synchronizer transmit MBs on specific channel, an associating device may listen on another channel [5]. As a result, the associating device may not obtain any MB for synchronization. Along with, the associating device also has to remain fully active to listen for MBs on its own synchronization channel for a longer time period. As a result, incurs associating overhead (i.e., incurs energy overhead and high latency) during network formation. Considering research analysis, it is observed that designing inefficient association scheme will result in degrading the performance of network. Especially, in highly dynamic network where device frequently join or leave a network [6].As a result incurring association overhead thus is expensive. This is the huge drawback of exiting approach. As network condition such as network density may change, an adaptive design is required to bring a tradeoff between energy overhead minimization and network performance requirement.

The objective of this work is to address the issue pertaining to rapid mobile device in TSCH network. A stochastic model is developed using Markov chain model to address the impact of node association process based on which this work presented a modified TSCH network for MANET. The modified TSCH network reduces the overhead of device mobility within TSCH network by introducing a novel modified beaconing for achieving Adaptive Routing (AR). The modified beacons use the acknowledgement packets, transmitted by MMD devices, to show the presence of MMDs. These modified beacons will be sent in arbitrary manner on a fixed channel. Thus, each MMD will choose an arbitrary time reference using predetermined time window in order to minimize the likelihood of packet collision with other acknowledgment packets. The proposed adaptive routing model minimize energy overhead and achieves good packet routing performance.

II. ADAPTIVE ROUTING MODEL FOR MANET USING MOBILITY ENABLED TSCH NETWORK

Here we present an adaptive and efficient routing model for MANET using TSCH (Time Slotted Channel hopping) network. Firstly, we present a TSCH network for mobile ad hoc network. Secondly, we present adaptive routing and beacon optimization model for MANET using TSCH network.

a) TSCH network for MANET:

The TSCH network introduce a novel idea of channel hopping and it's also introduce a fast association method using modified beacons (MBs). Here each MANET device has to gather information about which channel the MBs are broadcasted. This is because MB's are dependent on channel frequency operating value. The channel frequency are computed using absolute slot ID (ASI) which behaves a counter for each lapsed time slot and time slot has distinctive ASI parameter.

$$K_{chnl} = F_{lst}\left[\left(ASI + chnl_{offset}\right)\%G_{chnl}\right] \tag{1}$$

where, the K_{chnl} depicts the operating frequency that a mobile device will possess for association or transmission, F_{lst} is composed of list of frequency channel available, $chnl_{offset}$ is a predefined parameter that the device are constructed before initialization or association phase, and G_{chnl} parameter depicts the number of channel in the F_{lst}.

The TSCH protocol also describes data element (DE) that will be incorporated in to MB which composed of information/data for a device looking to associate the network.TheDE can describe the amount of slot frame and amount of link per slot frame along with channel offset which is composed of single bytes for byte for describing association selectivity parameter and 5 bytes describing ASI parameter. Further, it is composed of $macTimeslot$ which depicts the format of each time slot and it consumes up to twenty five bytes. This parameter must be presented for performing network initialization, for each association request reply but can be omitted to guarantee not exceeding the $aMaxPhyPktSize$.Lastly, the DE depicts the hopping sequence information which can also be eliminated to prevent exceeding the $aMaxPhyPktSize$. The parameter qT_F and qU_t represent slot frames size and the time slots size in each slot frame. Therefore, the MMD can broadcast MB in each mbL and mbL is obtained as follows

$$mbL = \sum_{j=1}^{qT_F}\sum_{k=1}^{qU_t} U_{jk} \tag{4}$$

where$U$ corresponds to the timeslot duration. Therefore to minimize the waiting time for mobile device association with network, we must minimize qT_F, since minimizing qU_t can impact or affects the association. Reducing qU_t will result in reduction of accessible overlapping channel for allowing MANET device and provide transmission with MMD.

b) Adaptive Routing and beacon optimization model for MANET:

To obtain or define the whether a mobile device will associate MANET or not, this work compute the session period that a mobile device will be residing within respective Region of Area (ROA) and prerequisite time to associate with MMD(MANET Mobile Device). In this work, we consider every ROA, a MANET device will constantly change it position in a specific direction and speediness. The likelihood of mobility can be represented as $^1/_q$ and evenly distributed. Therefore, the predictable residing time U_t elapsedin a ROA of a MMD that has transmission coverage$S$considering certain dBM is approximated using following expression,

$$U_T = \frac{\sum_q u_q}{q} \tag{3}$$

where, n is the quantum of likely paths or trajectories in a ROA and u is the residing time of a given path in a ROA. As time is segmented in two stages, the requesting association time (i.e., the time requisite for associating the MMD) and associated session period.

The mobile device association behavior in TSCH network can be modeled as a stochastic model using Markov four states model. The likelihood $L_{mb}(t_f)$ of obtaining singleMBconsidering a frame slot $t_f$self-possessed with $qU_s$are described as follows

$$L_{mb}(t_f) = \sum_{k=1}^{qU_s}\binom{qU_s}{k}\left(\frac{1}{G_{chnl}}\right)^k\left(1-\frac{1}{G_{chnl}}\right)^{G_{chnl}-K} \tag{4}$$

where G_{chnl} depicts is the quantum of accessible channel. Then the likelihood (L_{mb})of MANET device obtainMB within certain specific slot index$u_{s_q}$is obtained as follows

$$L\left(u_{s_q}\right) = \frac{\left(1-\frac{1}{G_{chnl}}\right)^{G_{chnl}-K}}{G_{chnl}} u_{s_q} = 1,2, \ldots. \tag{5}$$

Significant factor to be seen are the difference among u_{s_q} and $u_{s_{q+1}}$ is always dependent on the instance of frame slot size and MB transmission where maximum iteration is j that is with respect to accessible resource size.

In our model for reducing energy overhead the average residing session periodare set greater than the prerequisite session period for communication.

$$U_t > U_{xt} + U_M + U_C \tag{6}$$

where U_{xt}depicts prerequisite session period for MANET device for joining the coordinating device post obtaining a MB, $U_M$depict session period depicting the mobile device is disconnected due to missing acknowledgement packets (which is related based on the amount of lost acknowledgment packets to broadcast the MANET device as new member and begin searching for MBS, and U_C is the time depicting the mobile device is in connected state. The likelihood $L_{mb}(t_f j)$ that MANET device obtain MBconsidering certain precise communication slots are attained frame slot j is obtained as follows

$$L_{mb}(t_f j) = \frac{1}{G_{chnl}-(j-1)} * \prod_{y=0}^{J-1} 1 - \frac{1}{G_{chnl}-y}, \quad for\ j \neq 1 \tag{7}$$

The likelihood β of leaving a ROA is obtained based on the location of a mobile device with restive to MMD position and whether it moving toward or away to ROA is obtained as follows

$$\beta_{,} = \frac{S_{dBm} - E_{RSSi}}{2S_{dBm}}, \quad RSSI_{u+1} < RSSI_u \tag{8}$$

$$\beta_{,,} = \frac{S_{dBm} + E_{RSSi}}{2S_{dBm}}, \quad RSSI_{u+1} > RSSI_u \tag{9}$$

where, S_{dBm} is the maximum range of communication of MMD for a given transmission power in dBm and E_{RSSi} is the distance of mobile device from a MMD which is obtained using $RSSI$ of the obtained acknowledgement packet from the MMD.

This work further identify the likelihoodγ that a MANET device obtain easy access to overlapping transmission link, we extract appropriate parameter that a MMD can offer, as: expected number of mobile device (F_n) moving toward a ROA at a given t_f, number of links shared (shd), number of dedicated links (M_E), and number of device attached (B_q) to the MMD.

$$\gamma = \frac{shd}{F_n + (B_q - M_E)}, \quad for\ M_E \leq B_q \tag{10}$$

Furthermore, the likelihood μ that a mobile device obtains an acknowledgment back is describes as follows

$$\mu = 1 - (\omega_{qBd1} + (1 - \gamma)) \tag{11}$$

Here the mobile device will not come back to C state once mobile device get into the qBd state, since the MMD has enough shared links. As a result, from state qBd_j, the device will either directed to states H or to states k.

Each slot frame receives an added free time h_u that aid in utilizing more resources. Thus affecting in increasing the number of node association that can be handled using Eq. (11). Where h_u is formulated as follows

$$h_u = \sum_{n=1}^{B_q} (TrsRecOffset + TrsTrnsAktDel + TrnsAkt)_n \tag{12}$$

For a mobile devices to describe it has been eliminated or removed from the MANET (inacceptable acknowledgment) at instance y, the device may turn ON its radio and starts scanning passively for acknowledgement packets on frequency channelG_{Akt}. In our work, the waiting time (x) of MANET device requesting for associating a MMD with only two consecutive slot frames and start transmitting data within third slot frame. PostM_u, the mobile device sends its connection request and wait for certain instance u_l (time desired for a node to reply to a request) and then obtains the connection request that classifies the synchronization param needed for MANET device for associating a MANET. This packets is composed of ASI, assigned $u_t$by which a device can send its data within a slot frame schedules, current session slot and lastly the acknowledgment session period that describes its session instance of MMD for sending the acknowledgment packets for respective devices. The M_u is computed as follows

$$M_u = (T_f - U_{akt}) + U_{MN} \tag{13}$$

where U_{akt} is random time within $X_{Akt}$to transmit acknowledgement packets,X_{Akt}depicts whether their transmission is successfully received,U_{MN} is the random time within X_{MN} to turn radio ON and listen for any association request, and X_{MN} is the time taken for MMD listening for association request. Dependency on arbitration with predefined time aid in minimizing likelihood of collision and the MANET will turn its radio ON within M_u for describing presence of new MMD beaconing within higher radio signal strength indicator to guarantee more residing time. Our AR model will minimize energy overhead and achieve good packet routing performance and utilize resource efficiently with high throughput which experimentally shown in next section.

III. SIMULATION RESULT AND ANNALYSIS

The experiment is conducted on 6TiSCH simulator. The 6TiSCH simulator is written in using python programming language by the associates of 6TiSCH WG [7] and it is open source. It composed of existing model[8] and proposed AER model is incorporated into 6TiSCH simulator. The parameter utilized for experiment analysis are tabulated in TABLE I. The parameter used are according to industrial environment condition where traffic are bursty in nature [9]. The experiment are conducted for evaluating outcome of proposed AR over exiting TSCH based scheduling and routing model in terms of energy overhead and packet routing performance.

a) Packet routing performance evaluation of AR over existing approach:

This section describes experimental outcome of $AR$with respect to existing scheduling and routing approach in terms of packet routing performance such as packet success ratio, throughput and packet drop rate considering varied packets and transmission rate. Fig. 1 determines the packet success ratio comparison between AR and existing model for different transmission rates in Mbps. From the Fig. 8 it is clearly visible that existing technique can perform satisfactory for lower transmission rate. However, for higher transmission rate, this technique is highly insufficient. On the other hand, the AR model performs far better for all the transmission rates. An average enhancement of 24.66% is attained using proposed AR model with respect to existing TSCH based scheduling and routing model considering packet success ratio considering varied transmission rate.

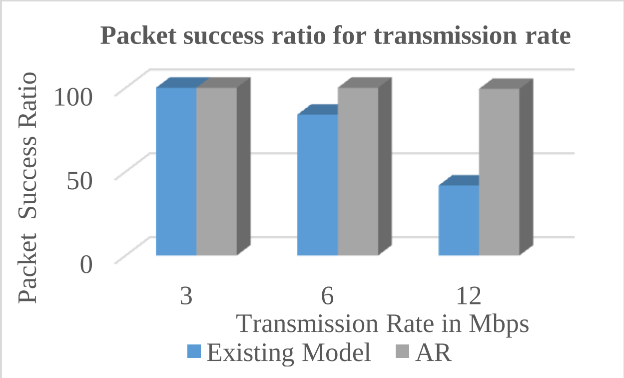

Fig. 1. Packet success ratio performance evaluation considering varied transmission rates

Fig. 2 determines the throughput of the network for AR and existing model for different transmission rates in Mbps. It is clearly seen from Fig. 2 that throughput of our AR model is much higher than the existing technique of throughput considering different transmission rates. It is clearly visible from the Fig. 2 that the existing algorithm perform satisfactory till the transmission rate of 3 Mbps. However, it underperforms for higher transmission rate and throughput remains almost similar for all the further transmission rates whereas the proposed scheduling algorithm perform satisfactory for all the transmission rates till 12 Mbps.

An average enhancement of 24.895% is attained by proposed AR model over existing TSCH based scheduling and routing model in considering throughput.

Fig. 3 determines the amount of packet is being dropped out of cumulated amount of packet being transmitted using AR and existing technique. Using the existing technique the number of dropped packets are very high in comparison with total transmitted packets and number of dropped packets increases as number of transmitted packet are increased. However, the amount of dropped packet using the AR technique are minimum. The proposed AR model reduces packet drop by 66.28% over existing model.

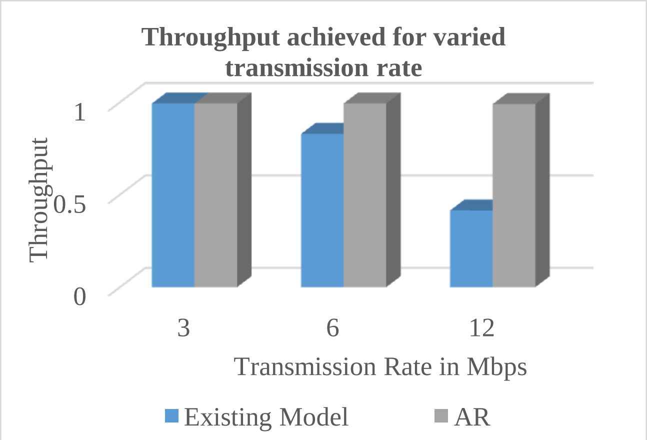

Fig. 2. Throughput performance evaluation considering varied transmission rates

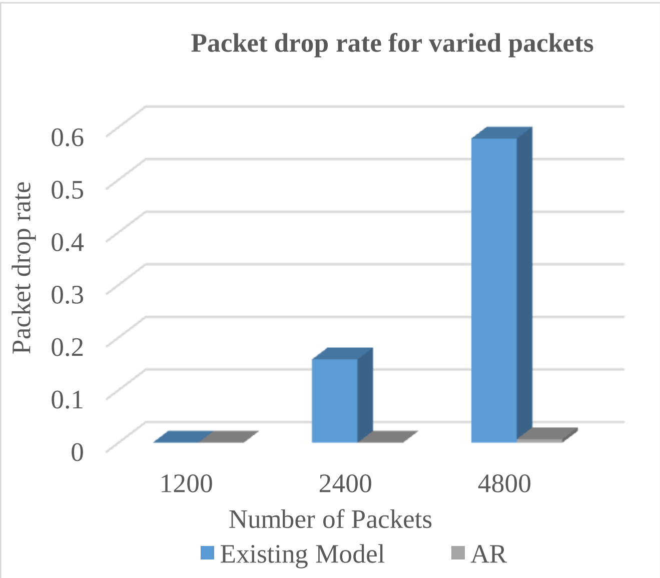

Fig. 3. Packet drop rate performance evaluation considering varied packets

b) Energy overhead performance evaluation of AR over existing approach:

This section describes performance evaluation of *AR* with respect with existing TSCH based routing and scheduling approach with respect to energy efficiency considering different packets and transmission rate. Energy overhead or consumption incurred considering varied transmission rate by both AR and existing model is shown in Fig. 4. The transmission rate is varied from 3 to 12. The outcome shows AR reduces energy consumption by 26.62%, 2.12%, and 27.98% over existing approaches considering 3, 6, and 12 respectively. An average energy overhead minimization of 18.9% are attained using AR with respect with existing TSCH based scheduling and routing approach considering varied transmission rate. The result achieved described good outcome using AR over existing scheduling and routing approach in terms of energy overhead minimization considering varied transmission rate.

Similarly, energy overhead or consumption incurred considering varied packets by both AR and existing model is shown in Fig. 5. The packet is varied from 1200 to 4800 packets. The outcome shows AER reduces energy consumption by 4.471%, 0.272%, and 22.83% over existing approaches considering 1200, 2400, and 4800 packets respectively. An average energy overhead minimization of 9.18% are attained using AR with respect with existing TSCH based scheduling and routing approach considering varied packets. The result attained describes good outcome attained using AR with respect with existing scheduling and routing approach in terms of energy overhead minimization considering varied packets.

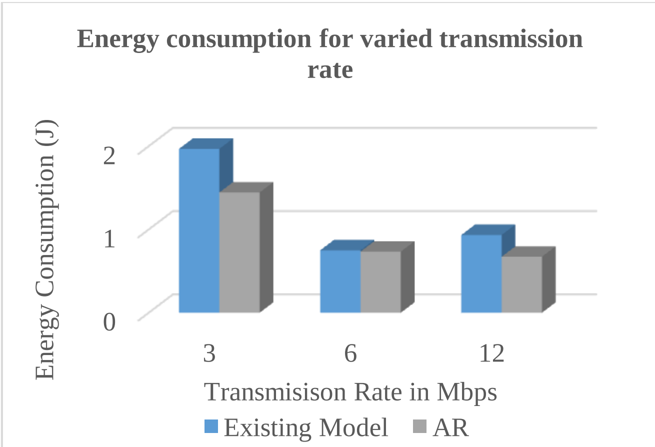

Fig. 4. Energy consumption performance evaluation considering varied transmission rate

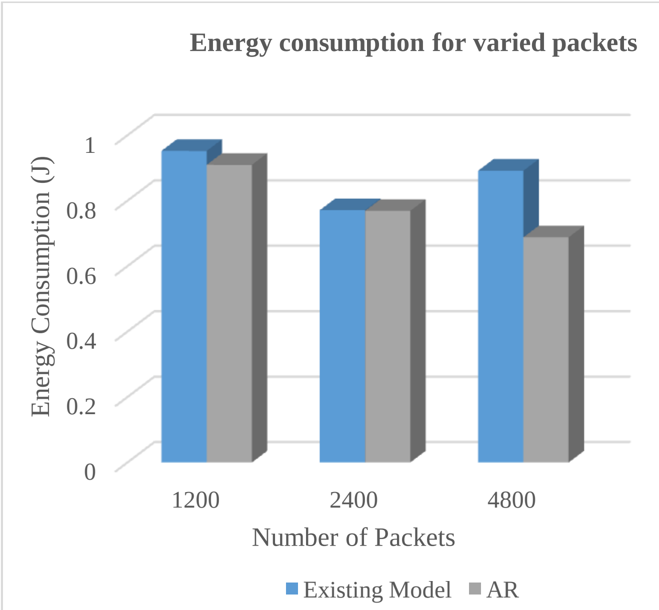

Fig. 5. Energy consumption performance evaluation considering varied packets

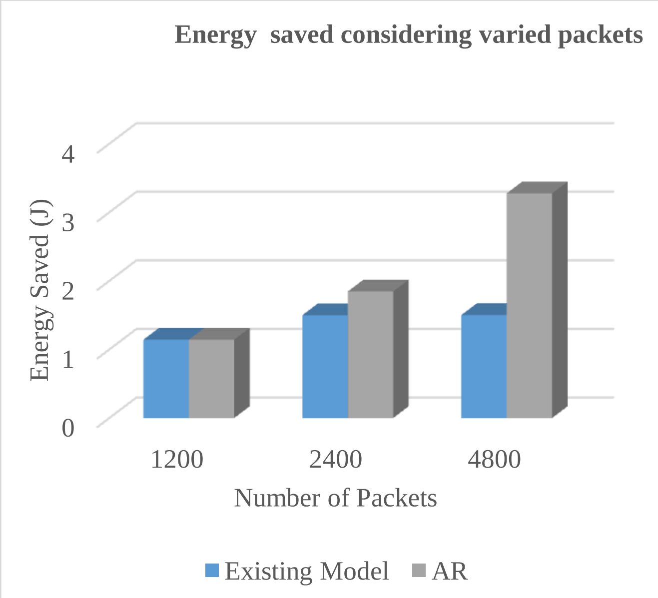

Fig. 6. Energy saving performance evaluation considering varied packets

The energy saving of AR over exiting approach is shown in Fig. 6, an energy saving of 0.08%, 18.71%, and 54.16% is achieved by AR over existing approach considering 1200, 2400, and 4800 packets respectively. An average energy saving of 24.31% is achieved by AR over existing approach considering varied packets. The outcome shows significant performance achieved by AR over existing approach in terms of energy saving considering varied packets.

IV. CONCLUSION

This paper presented an adaptive routing model for mobility enabled TSCH network. Firstly, we present a TSCH network for mobile ad hoc network. Then, we presented an adaptive routing model and beacon optimization for MANET using modified mobility enabled TSCH network. Experiment are conducted to evaluate performance of AR over existing approaches in terms of packet drop rate, packet throughput, and packet successful ratio, energy overhead, and energy savings considering varied packets and transmission rate. An average packet successful ratio and throughput improvement of 424.66% is achieved considering varied transmission rate by AR over exiting model. An average drop rate reduction of 66.28% reduction is achieved considering varied packets by AR over exiting approach. An average energy overhead reduction of 9.18% and 18.9% is achieved considering varied transmission rate and packets respectively by AR over existing approach. An average energy saving of 24.31% is achieved considering varied packets by AR over existing approach. The AR good trade-off between energy overhead minimization and routing performance requirement of future real-time application. The result shows robustness and scalability performance of AR. The future work would consider performance evaluation considering higher packets and transmission rate and further optimize the TSCH network for achieving better performance.

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