Message Transmission Scheduling for Multi-hop Wireless Sensor Network with T-Shaped Topology

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Message transmission scheduling for multi-hop wireless sensor network with T-shaped topology

Linh Vu Nguyen, Masahiro Shibata and Masato Tsuru

Abstract In multihop wireless sensor networks, packets are periodically generated at each node in every cycle period time and forwarded along lossy wireless links between adjacent nodes toward one of the gateways through which the packets can reach a central data collection server. To cope with frequent packet losses, we consider a TDMA-based packet scheduling with redundant transmissions. In our previous work, we propose an optimal scheduling for the tandemly-arranged network topology with two gateways at the both edges of the network; which is not always realistic. Therefore, in this paper, we extend the research to the T-shaped network topology with three gateways. We derive a static time-slot allocation for T-shaped topology, which maximizes the theoretical probability that all packets are successfully delivered to the server with the basic redundant transmission scheme in a limited cycle period; and show its benefit through numerical results. This extension significantly increases the applicability of our optimal scheduling scheme.

1 Introduction

Multi-hop wireless networks are in widespread use nowadays due to their economy and flexibility in deployment and operation, which are used to connect or cover communication nodes in an area where single-hop wireless networking is costly or not

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sufficient to work. In particular, to support emerging IoT and Cyber-Physical System technologies, multi-hop wireless sensor networks are of practical importance, e.g., for environmental surveillance or facility monitoring in a large field area, when a commercial communications infrastructure is unavailable or too costly. However, multi-hop wireless networks in the field often suffer from frequent packet losses due to attenuation and fading on each link as well as radio interferences of simultaneous transmissions among nodes. Furthermore, in typical multi-hop sensor network scenarios, since data packets generated at each node should be forwarded toward one of “gateways” through which the packets can reach a central data collection server, links near a gateway are likely congested to forward all packets generated by upstream nodes. To cope with frequent packet losses and avoid conflicts of simultaneous packet transmissions, our work in this paper assumes a centralized TDMA (Time Division Multiple Access)-based packet transmission scheduling with a redundant transmission scheme.

Our work is motivated by facility monitoring scenarios, in which surveillance sensors are stationary arranged along a road, river, or electricity pylons network. Therefore, we focus on typical static topologies to cover a connected facility such as a tandem (line) topology and a T-shaped topology, instead of an arbitrary complex or dynamic topology of networks. In our previous work, we focus on tandemly-arranged topology networks with two gateways at the both edges of the network. [1, 2, 3]. On the other hand, in this paper, we extend the research to T-shaped topology networks with three gateways. This extension significantly increases the applicability of our scheduling scheme. In our scheme, a central management server, e.g., as data collector, is assumed and it derives a static global time-slot allocation for T-shaped topology networks. The derived schedule is optimal in terms of the theoretical probability that all packets are successfully delivered to the server with the basic redundant transmission scheme. Note that a derived transmission schedule should be distributed to each node in some way. A scheme to exchange and share the involved information is necessary (i) for a server to know a network topology and related information such as data transmission rates (bandwidths) of links, distances between nodes, packet loss rates on links, and packet generation rates at nodes; and (ii) for each node to know a derived transmission schedule. This problem, i.e., how to implement an efficient and reliable control plane in wireless multi-hop networks, is of interest and importance; however it is out-of-scope of this paper and remains as future work.

On conflict-free TDMA scheduling for multi-hop wireless networks, there are a number of studies in literature. A TDMA-based end-to-end delay aware transmission scheduling was investigated in [4]. Centralized algorithms for TDMA-based scheduling for wireless sensor networks with a few central data collectors were proposed in [5]. Routing and scheduling in wireless mesh networks with multiple gateway nodes connected to a central server were studied in [6]. However, those work focus on conflict-freeness and do not deal with optimal redundant transmissions to recover lost packets. In addition, in contrast to general and complex topologies they dealt with, the T-shaped topology allows us to handle the path model for routing and the conflict graph easier, which contributes a simpler formulation for optimization in both scheduling and routing.

2 Sensor network model with T-shaped topology

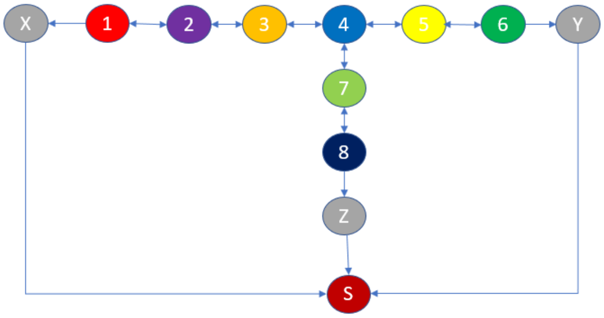

Fig. 1 T-shaped network topology of this research

This study assumes multi-hop wireless sensor networks of the T-shaped topology with three gateway at the edges as illustrated in Fig. 1. The sensor nodes and links are numbered separately from left to right and from up to down (starting from 1). The packet loss rate of link j is defined as $q_j \, (0 < q_j < 1)$, and the packet generation rate of node i is defined as integer r_i. Each link is lossy and half-duplex; a packet transmission at a node affects both links connected to the node (e.g., with omnidirectional antenna); the link layer does not provide any ARQ and transmission power adaptation mechanisms. Node i generates r_i packets at (or before) the beginning of each one cycle period of D and those packets are forwarded toward the gateway either X or Y or Z, which are then sent to central server S. Each packet is equally sized. Central server S knows the values q_j and r_i for any link j and node i as well as a network topology with related information such as data transmission rates of links and distances between nodes.

Designing a global static time-slot allocation includes two issues; how much it can utilize a limited number of time-slots in redundant packet transmissions by considering the upstream-downstream relationship among nodes and the packet loss rate of each link; and how much it can avoid radio interference among near-by nodes in simultaneous transmissions.

To design a packet transmission schedule, it should be decided to which direction the packets are transmitted on each link. We call it “path model”; many different path models can be considered by choosing the locations of the separation links and the directions of packets. For example, we create path models that are divided at two separation (unused) links. It is called l-r-d model where l, r, and d represent the number of nodes whose packets are forwarded to gateway X, Y, and Z, respectively. Node group S_X is the set of nodes whose packets are forwarded to X. Node group S_Y is the set of nodes whose packets are forwarded to Y. Node group S_Z is the set of nodes whose packets are forwarded to Z. For example, as shown in Fig. 2, if the separation links are between nodes 3 and 4 and between nodes 4 and 5, the path model is 3-2-3 model. Node group S_X has 3 nodes whose packets are forwarded to gateway X (S_X = 1,2,3), node group S_Y to gateway Y (S_Y = 5,6), and node group S_Z to gateway Z (S_Z = 4,7,8). As shown in Fig. 4, if the separation links are between nodes 2 and 3 and between nodes 4 and 7, the path model is 2-4-2 model.

The proposed packet transmission scheduling consists of the following steps. On routing (i.e., the packet transmission direction on each link), we consider and compare all reasonable path models. On time-slot allocation, for each path model, we derive a static time-slot allocation to maximize the theoretical probability that all packets are successfully delivered to the server with the basic redundant transmission scheme in a limited time duration. To prohibit near-by nodes from harmful simultaneous transmissions, a static interference avoidance policy based on the distance between nodes is adopted. All path models are examined one by one with each optimal slot allocation to decide a best combination of a path model and a slot allocation. To make the formulation simple, we assume all packets have the same size and all links have the same unit data transmission rate. Therefore, let U be the time duration of one time-slot, i.e., one packet can be transmitted on a link between adjacent two nodes in U unit time, the total number T of slots in one cycle period is equal to D/U. In this setting, $s_{i,j}$ slots are allocated, i.e., available to use, for a packet generated by node i to pass through on link j within the total time-slots of T. In other words, each node redundantly transmits its possessed packets (that is originally generated by node i) on downstream link j in $s_{i,j}$ times. If a packet is lost somewhere in upstream between that node and the node which generated the packet, the slots allocated to the lost packet are used for the next packet.

In deriving a time-slot allocation, we define and solve a maximization problem that theoretically maximizes the success probability of delivering all packets to either one of three gateways under given packet loss rates on links and packet generation rates at nodes, within T time-slots in total in one cycle period. Let M_i be the success probability of delivery for one packet generated by node i. The aim is to maximize the product $\prod_{i=1}^{n} M_i^{r_i}$ subject to the number T of available time-slots in one cycle period where n is the number of sensor nodes.

3 Path models and Time-slot allocation

3.1 Static slot allocation for 3-2-3 model

Fig. 2 shows the 3-2-3 path model on a T-shaped topology network with 8 sensor nodes shown in Fig. 1. In this path model, since nodes 3 and 7 are in the radio propagation distance, 3 and 4 cannot send at the same time (to avoid an interference at node 7). Since nodes 5 and 7 are in the propagation distance, 5 and 4 cannot send at the same time (to avoid an interference at node 7). On the other hand, 3 and 5 and 7 can send to its next node at the same time. We have two patterns for message transmission scheduling. In pattern 1, we prioritize the transmission in groups S_X (node 3-2-1) and S_Y (node 5-6) first, then group S_Z (node 4-7-8). In pattern 2, we prioritize group S_Z first, then groups S_X and S_Y. In other words, in pattern 2, the most upstream side node toward Z (i.e., node 4) can start its transmission earlier than the most upstream nodes toward X and Y (i.e., nodes 3 and 5).

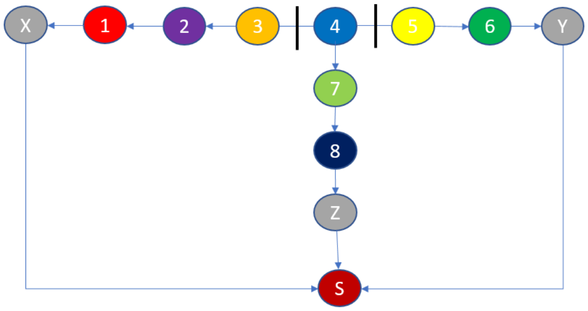

Fig. 2 The 3-2-3 path model in the network topology in Fig.1

Fig. 3 shows a transmission schedule of pattern 2 on 3-2-3 model. To formulate the problem to be solved, let $s_{i,j}$ be the number of slots allocated to redundantly

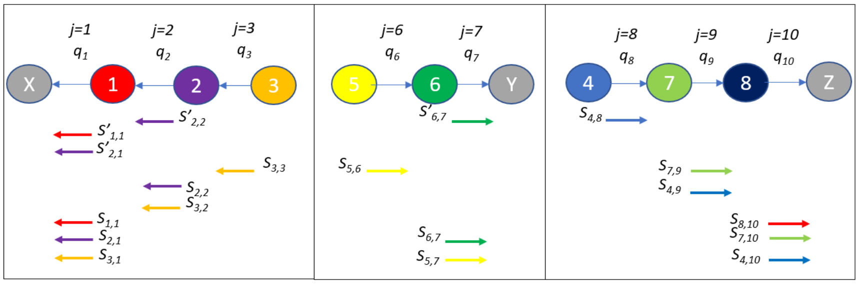

Fig. 3 Transmission scheduling on 3-2-3 model (pattern 2, all r_i=1)

transmit a packet generated by node i on link j, q_j be the packet loss rate of link j, and r_i is the packet generation rate of node i. Note that we also introduce $s'_{i,j}$ to indicate the number of slots for an early stage transmission which happens before or at the same time of a transmission of the most upstream node in the path. The success probability of delivery of a packet generated by node i with redundant transmissions $\{s_{i,j}\}$ are denoted by M_i, and can be calculated as follows.

In group S_X, $s_{2,2}$ and $s'_{2,1}$ cannot be 0 at the same time, in any optimal schedule.

$$\begin{aligned} M_1 &= (1-q_1^{s_{1,1}+s'_{1,1}}), \\ M_2 &= (1-q_1^{s'_{2,1}+s_{2,1}})(1-q_2^{s'_{2,2}}) \quad \text{if } s_{2,2}=0, \text{ or} \\ &= (1-q_1^{s_{2,1}})(1-q_2^{s'_{2,2}+s_{2,2}}) \quad \text{if } s'_{2,1}=0, \\ M_3 &= (1-q_1^{s_{3,1}})(1-q_2^{s_{3,2}})(1-q_3^{s_{3,3}}) \end{aligned} \tag{1}$$

In group S_Y,

$$\begin{aligned} M_5 &= (1-q_6^{s_{5,6}})(1-q_7^{s_{5,7}}) \\ M_6 &= (1-q_7^{s_{6,7}+s'_{6,7}}) \end{aligned} \tag{2}$$

In group S_Z,

$$\begin{aligned} M_4 &= (1-q_8^{s_{4,8}})(1-q_9^{s_{4,9}})(1-q_{10}^{s_{4,10}}) \\ M_7 &= (1-q_9^{s_{7,9}})(1-q_{10}^{s_{7,10}}) \\ M_8 &= (1-q_{10}^{s_{8,10}}) \end{aligned} \tag{3}$$

Hence the success delivery probability of 3-2-3 model:

$$M(\mathbf{s}) = \prod_{j=1}^{8} M_j^{r_j}$$

where $\mathbf{s} = \{s_{i,j}, s'_{i,j}\}$. The problem we need to solve is

$$\begin{aligned} \max M(\mathbf{s}) \text{ subject to } T &= r_2 s'_{2,2} + r_1 s'_{1,1} + r_2 s'_{2,1} + r_3 s_{3,3} + r_2 s_{2,2} + \cdots + r_3 s_{3,1}, \\ T &= r_6 s'_{6,7} + r_5 s_{5,6} + r_6 s_{6,7} + r_5 s_{5,7}, \\ T &= r_4 s_{4,8} + r_7 s_{7,9} + r_4 s_{4,9} + r_8 s_{8,10} + r_7 s_{7,10} + r_4 s_{4,10}. \end{aligned} \tag{4}$$

For conciseness, we explain how to solve it only in case of $r_i = 1$, since the extension is somewhat straight-forward. Assuming node group S_Z is a bottleneck, we adopt the pattern 2, that is, solve a sub-problem for group S_Z first to find the number of transmissions $\{s_{i,j}\}$ that maximize the success delivery probability. That is, maximizing $M_4 M_7 M_8$ subject to

$$T = s_{8,10} + s_{7,9} + s_{7,10} + s_{4,8} + s_{4,9} + s_{4,10} \tag{5}$$

To solve group S_Z, the Lagrangian multiplier is applied to a relaxation version to derive equations (6) where $s_{i,j}$ are not restricted to natural numbers and α is an adjunct variable.

$$\begin{gathered} s_{4,10} = s_{7,10} = s_{8,10} = -\frac{\log(1-\alpha\log(q_{10}))}{\log(q_{10})} \\ s_{4,9} = s_{7,9} = -\frac{\log(1-\alpha\log(q_9))}{\log(q_9)}, \quad s_{4,8} = -\frac{\log(1-\alpha\log(q_8))}{\log(q_8)} \end{gathered} \tag{6}$$

From Eq.(5), we have

$$T = s_{4,8} + 2s_{4,9} + 3s_{4,10} \tag{7}$$

where α can be numerically solved to get the real number solution of the relaxed problem. Based on that, we should seek an appropriate natural number solution as the number of allocated slots, by examining natural number solutions near the derived real number solution. Let $s^*_{i,j}$ be the natural number solution finally obtained. Let $\mathbf{a}$ be $s^*_{4,8}$.

To solve group S_Y using $\mathbf{a}$, we tentatively maximize M_5M_6 without considering $s'_{6,7}$ subject to

$$T = s_{5,6} + s_{5,7} + s_{6,7} \tag{8}$$

Similarity to group S_Z, we derive

$$s_{5,7} = s_{6,7} = -\frac{\log(1-\beta\log(q_7))}{\log(q_7)}, \quad s_{5,6} = -\frac{\log(1-\beta\log(q_6))}{\log(q_6)} \tag{9}$$

By solving Eq. (8) with Eq. (9), we get $s^*_{i,j}$ as its solution. Based on $s^*_{i,j}$, the true solution can be computed as follows. If $s^*_{5,7} \geq \mathbf{a}$, the solution is

$$s_{5,6} = s^*_{5,6}, \quad s'_{6,7} = \mathbf{a}, \quad s_{6,7} = s^*_{5,7} - \mathbf{a}, \quad s_{5,7} = s^*_{5,7} \tag{10}$$

However, if not (i.e., $s^*_{5,7} < \mathbf{a}$), we need to solve another equation

$$T - \mathbf{a} = s_{5,6} + s_{5,7} \tag{11}$$

and get its solution $s^{**}_{i,j}$. Based on $s^{**}_{i,j}$, the true solution is:

$$s_{5,6} = s^{**}_{5,6}, \quad s'_{6,7} = \mathbf{a}, \quad s_{6,7} = 0, \quad s_{5,7} = s^{**}_{5,7} \tag{12}$$

Finally to solve group S_X using $\mathbf{a}$, we tentatively maximize $M_1M_2M_3$ without considering $s'_{1,1}$, $s'_{2,1}$, $s'_{2,2}$ subject to

$$T = s_{1,1} + s_{2,1} + s_{2,2} + s_{3,1} + s_{3,2} + s_{3,3} \tag{13}$$

where its solution $s^*_{i,j}$ can be get in the same way. Let $\mathbf{b}_3$ be $s^*_{3,3}$, $\mathbf{b}_2$ be $s^*_{3,2}$, $\mathbf{b}_1$ be $s^*_{3,1}$. There are five cases: (c1) $\mathbf{b}_2 \geq \mathbf{a}$; (c2) $\mathbf{b}_2 < \mathbf{a}$ and $\mathbf{b}_1 \geq \mathbf{a}$; (c3) $\mathbf{b}_2 + \mathbf{b}_1 \geq \mathbf{a}$; (c4) $\mathbf{b}_2 + 2\mathbf{b}_1 \geq \mathbf{a}$; (c5) $\mathbf{b}_2 + 2\mathbf{b}_1 < \mathbf{a}$. For example, in case (c1), the true solution is:

$$s_{3,3} = \mathbf{b}_3, \quad s'_{2,2} = \mathbf{a}, \quad s_{2,2} = \mathbf{b}_2 - \mathbf{a}, \quad s_{3,2} = \mathbf{b}_2 \tag{14}$$

$$s_{1,1} = s_{2,1} = s_{3,1} = \mathbf{b}_1, \quad s'_{1,1} = s'_{2,1} = 0 \tag{15}$$

Cases (c2) to (c4) can be solved in the same way. However case (c5) requires to solve other two equations independetly:

$$\mathbf{a} = s_{2,2} + s_{2,1} + s_{1,1} \tag{16}$$

$$T - \mathbf{a} = s_{3,3} + s_{3,2} + s_{3,1} \tag{17}$$

3.2 *Static slot allocation for 2-4-2 model*

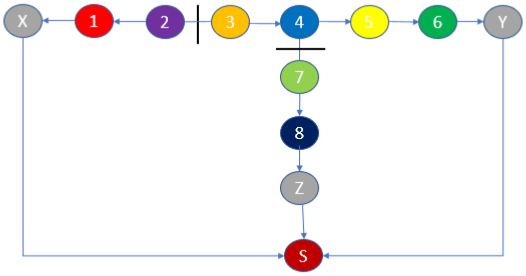

Fig. 4 The 2-4-2 path model in the network topology in Fig.1

Fig. 4 shows the 2-4-2 path model on a T-shaped topology network with 8 sensor nodes shown in Fig. 1. In this path model, since nodes 4 and 7 are in the radio

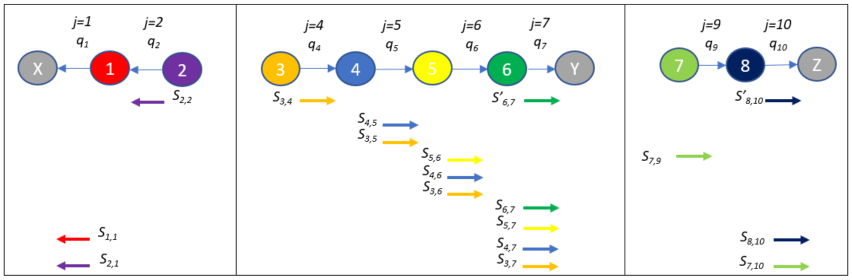

Fig. 5 Transmission scheduling on 2-4-2 model (pattern 1, all r_i=1)

propagation distance, 3 and 7 cannot send at the same time (to avoid an interference at node 4). Since nodes 5 and 7 are in the propagation distance, 4 and 7 cannot send at the same time (to avoid an interference at node 5). On the other hand, 5 and 7 can send to its next node at the same time. We have two patterns for message transmission scheduling. In pattern 1, we prioritize the transmission in group S_Y (node 3-4-5-6) first, then group S_Z (node 7-8). In pattern 2, we prioritize group S_Z first, then group S_Y. Note that group S_X is independet and can be solved separately.

Fig. 5 shows a transmission schedule of pattern 1 on 2-4-2 model. The success probability of delivery in each node group can be calculated as follows. In group S_X,

$$M_1 = (1-q_1^{s_{1,1}}), \quad M_2 = (1-q_1^{s_{2,1}})(1-q_2^{s_{2,2}}) \tag{18}$$

In group S_Y,

$$\begin{aligned} M_3 &= (1-q_4^{s_{3,4}})(1-q_5^{s_{3,5}})(1-q_6^{s_{3,6}})(1-q_7^{s_{3,7}}) \\ M_4 &= (1-q_5^{s_{4,5}})(1-q_6^{s_{4,6}})(1-q_7^{s_{4,7}}) \\ M_5 &= (1-q_6^{s_{5,6}})(1-q_7^{s_{5,7}}), \quad M_6 = (1-q_7^{s_{6,7}+s'_{6,7}}) \end{aligned} \tag{19}$$

In group S_Z,

$$M_7 = (1-q_9^{s_{7,9}})(1-q_{10}^{s_{7,10}}), \quad M_8 = (1-q_{10}^{s_{8,10}+s'_{8,10}}) \tag{20}$$

Hence the success delivery probability of 2-4-2 model:

$$M(\mathbf{s}) = \prod_{j=1}^{8} M_j^{r_j}$$

where $\mathbf{s} = \{s_{i,j}, s'_{i,j}\}$. The problem we need to solve is

$$\begin{aligned} \max M(\mathbf{s}) \text{ subject to } T &= r_1 s_{1,1} + r_2 s_{2,1} + r_2 s_{2,2}, \\ T &= r_3 s_{3,4} + r_3 s_{3,5} + r_3 s_{3,6} + r_3 s_{3,7} + r_4 s_{4,5} + \cdots + r_6 s_{6,7}, \\ T &= r_7 s_{7,9} + r_7 s_{7,10} + r_8 s_{8,10} + r_8 s'_{8,10}. \end{aligned} \tag{21}$$

The 2-4-2 model can be solved in a similar manner as the 3-2-3 model. Assuming that either node group S_Y or S_X is a bottleneck, we adopt the pattern 1, that is, solve a sub-problem for group S_X and group S_Y first. Then based on the solution for group S_Y, we can solve a sub-problem for group S_Z.

4 Numerical results

On our example T-shaped topology network, we show a few numerical results to evaluate the performance of derived time-slot allocations in three different cases in terms of the setting of link loss rates $\{q_{i,j}\}$ shown in Table 1; packet generation rates are uniform ($r_i = 1$); the total number T of time-slots is $T = 15$ or $T = 30$. Highly lossy links (links with high loss rates) are located near gateway S_Y in case 1; near gateway S_X in case 2; and near gateways S_X, S_Y, and S_Z in case 3. Matlab is used to get the solutions of the maximization problems for the pattern 2 of path model 3-2-3 and the pattern 1 of path model 2-4-2 in the way described in Section 3. As performance metric, the Theoretical Upper-Bound (TUB) value and the Model-based Computed (COM) value are used. TUB is the theoretical maximum value of the objective function in the relaxed version of the maximization problem, which is a theoretical upper-bound of COM. COM is the computed probability of delivering all packets using an optimal slot allocation according to a natural number solution of the original integer-constraint maximization problem.

Table 1 Packet loss rate on each link

Case	q_1	q_2	q_3	q_4	q_5	q_6	q_7	q_8	q_9	q_{10}
1	0.2	0.3	0.2	0.2	0.1	0.5	0.4	0.2	0.2	0.3
2	0.5	0.4	0.2	0.2	0.2	0.2	0.1	0.2	0.2	0.3
3	0.4	0.5	0.3	0.3	0.2	0.5	0.4	0.2	0.4	0.5

Fig. 6 compares the performance, i.e., the probability of success delivery of packets generated by all nodes with $T = 15$ and 30, in pattern 2 of the 3-2-3 model (blue) and in pattern 1 of the 2-4-2 mode (orange). In cases 1 and 3, the 3-2-3 model clearly outperforms the 2-4-2 model. The pattern 2 in the 3-2-3 model is resilient to high loss rates near Y because node group S_Y uses only two links (links 6 and 7); at the same time, it is also resilient to high loss rates near Z because node group S_Z is prioritized to avoid a possible interference by node groups S_X and S_Y. In other words, this path model has a good balance, which can be the reason for better performances in cases 1 and 3. In contrast, the 2-4-2 model a little outperforms the 3-2-3 model. The pattern 1 in the 2-4-2 model is resilient to high loss rates near X because node group S_X uses only two links (links 1 and 2) and also is not interfered by other node groups. Those results clearly suggest the need to choose a best path model depending on the settings, and they also demonstrate the benefit of our proposed approach. Furthermore, not surprisingly, the ratios of COM values to TUB values are large in case of a small T ($T = 15$), because each difference between a real number and a natural number has a larger impact if the total number of slots is smaller.

Fig. 7 investigates the relationship between the probability of success delivery for each node and its location in case of $T = 15$. As expected, the probabilities of success delivery for the upstream nodes are generally lower than those of the downstream nodes along a path (i.e., in a node group). Note that the TUB value is based on an optimal real number solution that maximizes the probability of success

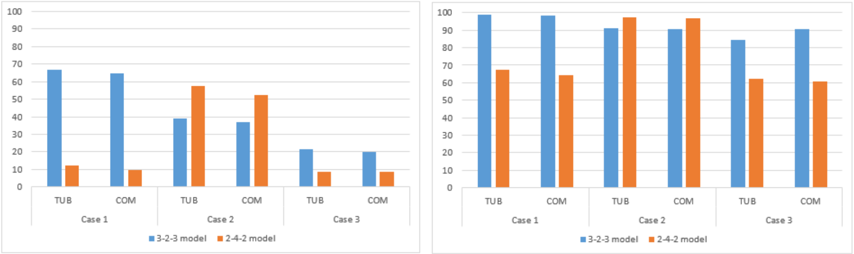

Fig. 6 Probability of success delivery for all nodes with T=15 and T=30

delivery for all nodes, so it does not always maximize the probability of success delivery for a specific nodes. As shown in Fig. 7, in per node comparison, a COM value can be larger than a TUB value for a specific node in some case.

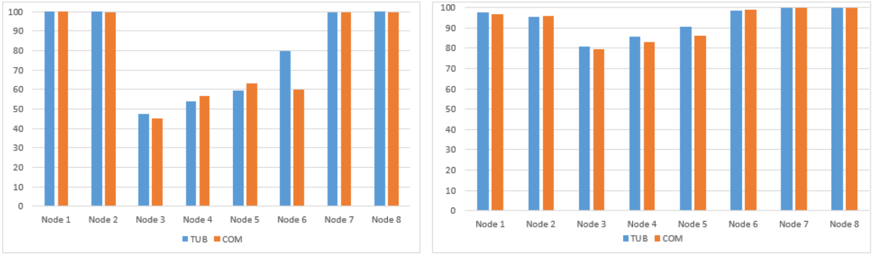

Fig. 7 Probability of success delivery for each node with $T = 15$; (left):2-4-2 model, case 1; (right): 3-2-3 model, case 3

5 Concluding Remarks

In this paper, a T-shape network topology with three gateways in typical multihop wireless sensor network scenarios is considered. Our proposed scheme derives a static optimal time-slot allocation in TDMA-based packet scheduling with redundant packet transmissions. In contrast to the tandemly-arranged topology, more diverse possible separation link locations and path models should be considered due to interferences between near-by nodes in different transmission paths (towards different gateways) in the T-shaped network topology.

As future work, we should improve the redundant transmission from the basic one just retransmitting each packet in $s_{i,j}$ times to a coding-based redundant transmission scheme with an inter-packet coding in transmitting multiple packets by multiple times, which was investigated in [2].

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References

1. Agussalim, M. Tsuru,“Message Transmission Scheduling on Tandem Multi-hop Lossy Wireless Links,” Proc. the 14th IFIP International Conference on Wired/Wireless Internet Communications (WWIC2016), pp.28–39, 2016.
2. R. Kimura, M. Shibata, M. Tsuru, “Scheduling for tandemly-connected sensor networks with heterogeneous link transmission rates,” Proc. the 34th International Conference on Information Networking (ICOIN2020), pp.590–595, 2020.
3. R. Yoshida, M. Shibata, M. Tsuru, “ Transmission scheduling for tandemly-connected sensor networks with heterogeneous packet generation rates,” Proc. the 12th International Conference on Intelligent Networking and Collaborative Systems (INCoS2020), 10 pages, to appear in 2020.
4. P. Djukic, S. Valaee, “Delay Aware Link Scheduling for Multi-Hop TDMA Wireless Networks,” IEEE Trans. on Networking 17(3):870–883, 2009.
5. S. Ergen, P. Varaiya,“TDMA scheduling algorithms for wireless sensor networks,” Wireless Networks, 16(4):985–997, 2010.
6. H. Tokito, M. Sasabe, G. Hasegawa, H. Nakano,“Load-Balanced and Interference-Aware Spanning Tree Construction Algorithm for TDMA-Based Wireless Mesh Networks,” IEICE Trans. Commun., E93B(1):99–110, 2010.
7. W. Li, J. Zhang, Y. Zhao,“Conflict graph embedding for wireless network optimization,” Proc. IEEE Infocom 2017, 9 pages, 2017.