Using a Token Approach for the MAC Layer of Linear Sensor Networks
Impact of the Redundancy on the Throughput

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Abstract: Wireless Sensor Networks (WSNs) consist of a large number of sensor nodes deployed in a wide area for monitoring applications. For some of these applications, as pipeline or road monitoring, wireless sensor nodes have to be deployed in a linear manner. We refer to these WSNs as Linear Sensor Networks (LSNs). Due to specificity of LSNs, MAC protocol designed for WSNs, as contention or TDMA based protocols, are often not suitable. Furthermore, wireless node deployment can provide a certain form of redundancy to prevent link or node failures. In this paper, we propose a token based MAC protocol for linear sensor networks in order to improve the network performance. We evaluate the effect of the redundancy on the number of packets delivered to the sink. We show that the redundancy induces a significant improvement both on the delivered traffic and on the FIFO queue size of the nodes.

1 INTRODUCTION

Wireless sensor networks (WSNs) are used to observe and react to events and phenomena in order to perform environmental monitoring. Very often, the geometry of the WSN is linear du to the monitored objects. A such geometry can be found in applications like detection of the presence of workers in a gallery of an underground mine (Li and Liu, 2009) or fluid leaks in water or oil pipelines (Jawhar et al., 2007)(Ted et al., 2012)(SunHee et al., 2009), in transmission of data between the wagons of a freight train (Zimmerling et al., 2008)(Wang et al., 2011)(Berlin and Van Laerhovenand, 2013), in the monitoring of roads, bridges and tunnels (Meng et al., 2008). In this paper, we refer to these networks as Linear Sensor Networks (LSNs). We focus on an application where packets have to reach a sink station arbitrarily located at the right end of the network. In LSNs each node has some neighbors to its left (they are called left neighbors) and to its right (they are called right neighbors). When sensor nodes are aligned on a straight line strictly forming a line, or a thin LSN as defined in (Jawhar et al., 2008), the network has to deal with two identified drawbacks: the link or node failure impacting the connectivity and the hidden terminal problem impacting the frame loss rate. This is why we are considering both the use of a token passing mechanism and the use of a light redundancy for LSN topology, providing alternative paths for the traffic. We assume a uniform placement of nodes, where the Sink is located at one end and a first node named Allocator at the other end. The allocator is in charge of providing tokens periodically.

Enhancing throughput and robustness, is one of the most important challenge in LSN. The density of the topology (number of neighbors of a current node) is low and depending on the propagation conditions and on the stability of the wireless links. This density will be used to introduce the redundancy of a LSN topology. If each node has only two neighbors, *ie* one on its right and one its left, the LSN is strictly linear. We called it 1-Redundancy LSN topology. When each node has 2*R neighbors, both R on its right and on its left, we are dealing with a R-Redundancy LSN topology allowing routing facilities. In this paper, we evaluate the impact of R on the traffic reaching the sink. The LSN topologies expose packets to the effect of the hidden problem and induce high latency (Noori and Arkani, 2008). So, the need of a suitable MAC protocol for network performance improvement is a real challenge in LSN. We propose a token based MAC protocol for LSNs deployed according a R-Redundancy topology (R varying from 1 to 3). The authorization to transmit is granted via the reception of a token ie a specific short frame. Tokens are pro-

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vided periodically by the first node named Allocator and then propagated from node to node. When a node is token holder it is allowed to transmit uplink traffic toward the sink and/or downlink traffic toward the Allocator. Packets are sent to the targeted node in a multi-hop manner following a path depending on the redundancy factor R.

This paper is organized as follows: Section 2 justifies the choice of our MAC protocol and presents the state of art on MAC protocol based on token for wireless sensor networks for throughput improvement. Section 3 introduces how the density allows us to define a R-Redundancy LSN and for each value of R, how to define the minimal distance between two consecutive tokens. Section 4 presents details about our token based MAC protocol. We show the mechanism allowing a token holder node to transmit traffic both toward the sink and toward the Allocator. Section 5 evaluates theoretically the impact of the redundancy on the optimum number of packets delivered to the sink. Section 6 confirms the impact of factor R on the optimal delivery rate, via NS2 simulation results. Section 7 discuss about the theoretical and simulation results obtained. This paper is concluded in Section Section 8.

2 STATE OF ART

The usual MAC protocol based on contention or TDMA are not suitable for LSNs. In the case of contention MAC protocols such as protocols based on Carrier Sense Multiple Access (CSMA) with or without RTS/CTS (Ndoye et al., 2013), 802.15.4 CSMA, SMAC, TMAC, encounter collision problems and induce congestion areas due to the hidden terminal problem. Thus, packet retransmissions decrease throughput at the sink. In the case of MAC protocols based on slotted access method, such as protocols based on Time Division Multiple Access (TDMA), TRAMA, FLAMA, they require a strict synchronization and/or a complex scheduling between nodes to avoid large unproductive time guard intervals. The drift of the clocks of the nodes decreases highly the throughput due to the loss of packets and induces energy wasting.

In the research literature related to the specificities of linear wireless sensor networks, LSNs are often used to drain data from a set of nodes (raw convergecast) in order to aggregate it in a sink. It is well known that a hop by hop routing of data packets to one or several specific sink nodes induces a kind of concentration of traffic along the path followed by the forwarded frames. At each hop along the path conducting to a sink, an additional local traffic is gathered to the data to be forwarded. This concentration of traffic increases progressively along this path and it may cause locally an overload of the medium. In (Noori and Arkani, 2008) authors show that the traffic increases progressively when it gets closer to the sink. Such areas are called congestion areas to point out the fact that the MAC has to deal with a local load exceeding the usual capacity of the medium. This causes several drawbacks:

- An overload of the FIFO of node within the congestion areas, inducing delays in the forwarding process and a risk of frame dropping due to FIFO overflow,
- An increasing of busy medium status returned by channel sensing (CCA operation),
- An increasing rate of collisions increased by the hidden terminal problem.

These two last phenomena cause losses of frames (collision or dropping). In the literature, this specific behavior has been identified early for solutions based on linear deployment of a wireless infrastructure made of 802.11 Access Points (Moutairou et al., 2009). For WSN applications, many research focus on the propriety of MAC protocol in order to avoid congestion and thus improve the throughput. In recent years, a lot of research focuses on token based protocols due to the limitation of classic MAC protocols (contention and TDMA). Nevertheless, most of these proposed protocols do not match in linear sensor network. ToKeN-TWiNs (TKN-TWN) described in (Liu et al., 2013a) is a high throughput data collection exploiting the advantages of TDMA. It eases the scheduling burden by using two tokens to arbitrate transmission activities. Access to the medium is organized by a centralized token passing mechanism. The sink node generates two types of tokens which are passed to two different top-subtrees, and a multi-channel approach is used to avoid interference. In (Liu et al., 2013b) an implementation and evaluation of TKN-TWN in term of throughput is presented. Authors show that in a binary-tree-formed network ToKeN-TWiNs throughput outperforms the throughput of collection protocol (Incel et al., 2012). This proposition was designed for WSNs deployed according to a tree topology and it loses a part of its interest for linear topology. In (Fan et al., 2012) authors present an Enhanced Dynamic Token Protocol (EDTP) using TPQ as described in WDTP (Xianpu et al., 2007). They show that in underwater acoustic WSN, EDTP performs better throughput than TDMA. In (Na et al., 2009) authors describe a Data Filtration-Aware MAC protocol for wireless Sensor Networks

(DF-MAC). It is a token-based MAC protocol based on TR-MAC (Na et al., 2007). Indeed, after nodes selection and the formation of a logical ring, data transmission is performed by using a token. It was shown that DF-MAC provides a better throughput than TR-MAC. Unfortunately, DF-MAC is designed for clustered network and cannot be relevant for LSNs. Even if the token based protocols presented above improve performance of classic or clustered WSNs, they are not designed for LSNs and they do not take advantage of the specificities of such a topology. The design of a MAC protocol for a LSN must consider a trade-off between the specificities of this kind of networks: topology, low density, small processing power, energy limitations, etc. We propose a MAC protocol based on a slotted access method needing a soft synchronization and taking advantage of linearity of the deployment of nodes. The use of a token to propagate the right to transmit is a way to avoid the constraints of a strict and global synchronization.

Before sending data frames, a current node has to wait the reception of a token from one of its neighbors. When this token reception occurs, this current node becomes Token Holder for a given amount of time SD (Shuttle Duration). Then this node can transmit uplink traffic toward the sink or downlink traffic toward the Allocator, details will be given in the next paragraph. The token frame contains information as the token generation period, the sleep and wakeup calendar. We evaluate our protocol in terms of throughput in order to show the impact of redundancy of linear network sensor on its behavior.

3 HYPOTHESES AND NETWORK TOPOLOGY

We outline now the details about the density of LSNs we are studying, the timing of MAC protocol we propose and the traffic model we use in this paper. In the following, we consider a one-dimensional LSN of N nodes uniformly placed over a length-L with equal distance d between two adjacent nodes. The kind of LSN we are going to use is depending on the density of the topology. If the radio range p and the distance d between nodes are such that d $<$ p $<$ 2d, each node has two neighbors (one to its left and one to its right). We are dealing with a strictly LSN having a density of 2 as shown in Fig. 1a. As defined previously it is a 1-Redundant LSN.

When p $>$ 2d, each node has at least 4 neighbors (two or more to its left and two or more to its right). For such topology, if a link is broken or a node is out of order it is still possible to forward the frames (mainly to the sink) by skipping the defective device. This kind of LSN is called R-redundant where R is the number of neighbors in each direction (right and left). A 2-redundant as shown in Fig. 1b. In the following, we focus on this kind of redundant LSNs, and we refer to them as 2-Redundant LSNs or 3-Redundant LSNs according to their density.

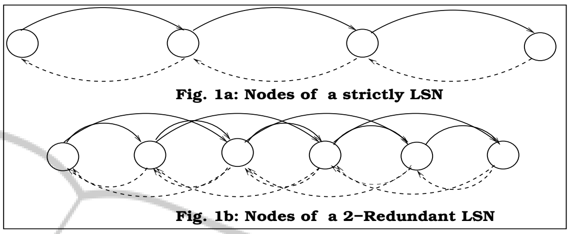

Figure 1: LSN topologies.

Each node has its own ID. In this paper we suppose the following points: (i) the node located at left end of the LSN is Node 1 and is the Allocator providing tokens, (ii) the node at the right side of Node I is Node I+1, (iii) the node located at the right end of the LSN is the Sink. The routing (or forwarding) scheme works as follows. Each node transmits data frames to its one-hop or R-hop neighbor according to the LSN topology.

In our simulation, the model we use for a current node is given in Fig. 2. A queue for packets is attached to each node; this queue is connected to the next node. In the following, we show the impact of the FIFO size and of the Shuttle Duration length on the number of packets delivered to the sink. Packets flow from the left to the right and a local load is injected into the queue of each node. For many reasons such as (i) retransmission credit exceeded (occurs when a node has transmitted five times the same data frame without receiving any acknowledgment), (ii) queue overload (occurs when the queue of the node is requested to keep too many packets), packets may not be received by the sink. We define the aggregate throughput as the number of packets received by the sink per unit of time. Throughput increases as the offered load provided by nodes (packets locally produced) increases. When the offered load reaches a certain threshold, the throughput does not increase any more. Sometimes, it can even start to decrease. We denote by t a period of time including several token periods, we can define the aggregate throughput of the LSN as:

S = $\frac{n*PacketsLength}{t}$ where n is the number of packets received by the sink during t. This throughput will be used for the evaluation of the efficiency of the Token MAC protocol according to the redundancy of the LSN.

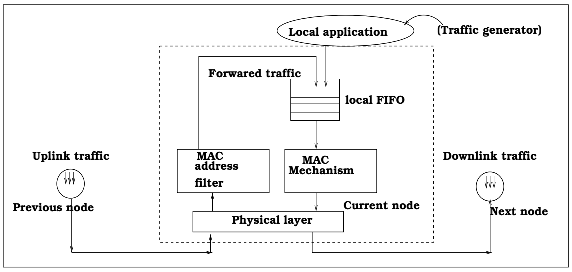

Figure 2: Node Model.

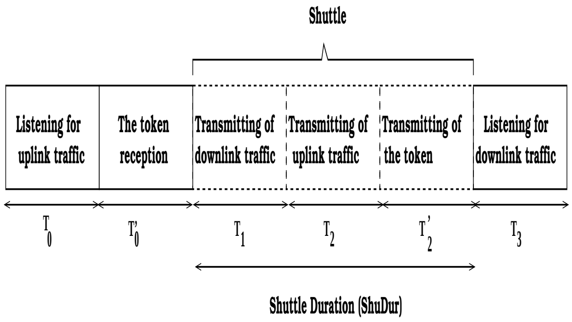

Figure 3: Example of token passing.

4 OUR PROPOSAL: TOKEN BASED MAC PROTOCOL

In this section we describe our proposal token based MAC protocol for LSNs.

4.1 Access Control

The token generation governing the access to the medium is initiated by the Allocator. It produces a token which circulates from node to node until it reaches the sink. In the following, the path followed by a token is always A, B, C, , Sink. Each node which receives a token is allowed to transmit during a given time called shuttle duration. So, a node has two major states: it is either token holder, or waiting for a token. In token holder state, the node can transmit differently data frames during the shuttle duration, according to three consecutive periods. (i) T_1: during this amount of time the node transmit data frames to its neighbor toward the Allocator. This traffic is called downlink traffic and comes from the sink. (ii) T_2: during this amount of time the node transmit data to the sink. This traffic is called uplink traffic. (iii) At the beginning of period T_2, the node being token holder passes the token to its neighbor at its right side and reaches the waiting for a token state. When there is no pending downlink traffic, a token holder node uses also T_1 for uplink traffic. When a node is in the waiting token state, it can either listen for uplink or for downlink packets coming from the sink, it can also switch off its radio to save energy. The temporal pattern of the activity of a current node is given on Fig. 3.

4.2 Periodicity of the Token Production

In this section, we define the minimal distance in term of nodes between two consecutive tokens in order to have several tokens circulating in the network at the same time. This distance must be calculated according to the transmission range of each node and on the possibility of having downlink traffic. In Fig. 4a, it is shown that in a strictly LSN with downlink traffic, the distance between two token holders is three nodes (four hops). The part of the LSN corresponding to nodes (A, B, C and D) as shown in can be considered as a cluster moving from node to node at each expiration of the shuttle duration. So, in the case of strictly LSN the size of the cluster (CluSize) is set to four hops. So if a reverse traffic is possible, a node is token holder at most only a quarter of its time. During three quarters of its time, it has to queue the traffic locally produced.
During the remaining quarter of its time, the node has to queue (in an interleaved manner) the local traffic in addition to the traffic forwarded by the previous node of the LSN. If the radio range allows the possibility to exchange with its two-hop neighbors, the spatial reuse becomes less efficient, as it requires an increase in the distance between two nodes being simultaneously in the token holding state.

As shown in Fig. 4b, for a 2-redundant LSN, two token holder nodes have to be separated by at least four nodes when the traffic is only for the sink, and by six nodes when a reverse traffic is possible. The size of the linear cluster (CluSize) is respectively 5 and 7. The minimal distance between two successive token holder nodes has a strong impact on the network performance and on the token production activity of the allocator. For a given token holding time (T_1 + T_2 + T'_2 as defined in Fig. 3), the minimal period of token production is given T_{Token} (min) = ShuDur x CluSize.

The time separating two consecutive tokens T_{Token} must be greater than T_{Token} (min); the choice of this period has to be done by considering the following factors: the energy autonomy of nodes, the profile of the offered traffic load, and so on.

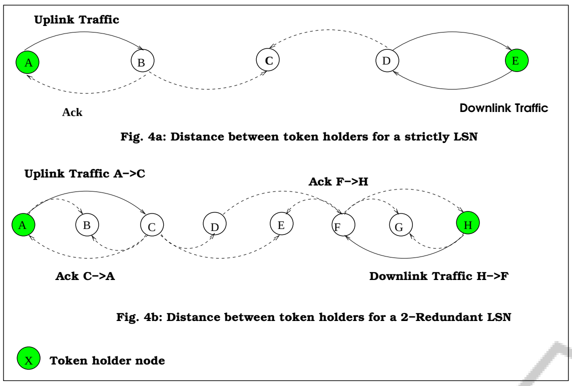

Figure 4: Distance between token holders.

5 MECHANISM OF TOKEN REDUNDANCY

The creation and the forwarding of a new token by the Allocator, allows the traffic of the nodes to be drained in a multi-hop manner. Each time a node is token holder, it can transmit (i) first the traffic towards the Allocator (downlink traffic), (ii) and during the remaining holding time, the traffic having the sink as destination (uplink traffic). Our choice to allow uplink and downlink traffic has an impact on the frequency of the token production. The distance between two consecutive nodes being token holder, expressed in number of hops, depends on the range of the radio link and on the distance between two consecutive nodes.

We can notice that the case of a strictly linear network, it is easy to show (Fig. 4) that the distance between two nodes being token holder is equal to four hops. That is to say 3 times the radio range expressed in number of hops plus 1. For a 2-redundant LSN, this distance increases to 7 hops (3 times the radio range plus 1) and for a 3-redundant LSN this distance reaches 10 hops (3 times the range plus 1).

Fig. 5.a and Fig. 5.b are used to introduce how the token passing is managed and how the path of data packets takes advantage of redundancy.In thesefigures, dashed arrows indicate the path systematically followed by the tokens: A $\longrightarrow$ B $\longrightarrow$ C ... $\longrightarrow$ Sink, blue arrows indicate the links which are simultaneously active at a given point in time. Fig. 5.a is for the 2-Redundant case, the traffic generated by node A is transmitted directly to node C to be concatenated with the traffic locally generated. This traffic is then forwarded to node E and so on. In such a network it can be seen that there is two branches (A, C, E, G) and (B, D, F,H) which converge towards the sink.

Fig. 5.b is for the 3-redundant case. The traffic generated by node A is transmitted directly to node D to be concatenated with the traffic locally generated. This traffic is then transmitted to node G and so on. In such a network, three branches converging towards the sink S, can be identified :(A, D, G, J), (B, E, H, K) and (C, F, I, L).This way of spreading the LSN traffic over these three branches has an impact on performance in terms of throughput. Let us consider Fig. 5.b when node A and node K are token holder, Node A is allowed to transmit data packets to D, and then its token to B, Node K will directly transmit its data packets to the sink and its token to L.We can notice two important things:

- The sink can receive data packets every time one of its neighbors is token holder. So for a 3-Redundant LSN, the same token gives 3 opportunities to the sink to receive data packets. Each token allows the sink S of Fig. 5.b to receive consecutively from J, K and L.
- The FIFO of each node being a neighbor of the sink must be large enough to store and forward the traffic of its branch. So for a 3-Redundant LSN, the evaluation of the FIFO size of a sink neighbor node is only governed by the traffic of its branch. The FIFO size of node K of Fig. 5.b is supposed to be larger enough to concatenate the traffic of nodes of the branch (A, D, G, J).

The two previous points will be used to evaluate the throughput capacity of a LSN according to the redundancy factor R. For R equals from 1 to 3, we want to estimate the optimal number of packets delivered to the sink for a given bit rate.

The word optimal is used here to point out the fact the FIFO size is adjusted to the shuttle duration to maximize the throughput and to avoid the loss of data packets. For this evaluation we chose to deal with medium sized data packets and we suppose that all the nodes of the same FIFO size for generality purpose. Each neighbor of the sink is token holder during just enough time to empty its FIFO. A direct consequence of this hypothesis is that the size of the FIFO equals the maximum number of data packets a token holder can sent before passing the token. In others words, the capacity of the shuttle is equal to the size of the node FIFO.

Let SC (Shuttle Capacity) be the number of packets a shuttle can carry. For a 1-Redundant LSN, the sink receives P packets by token, *ie* P packets for each time period of 4 ShuttleDurations(SD). The delivery rate of data packets to the sink is

Theoretical_Throughput(1)=$\frac{1*SC}{4*SD}$ expressed in packets per second

For a 2-redundant network and for each token, the sink receives S packets from its one hop neighbor but also S packets from its two hop neighbor. For such a case two consecutive tokens are separated by 7 Shuttle Durations. The delivery rate of data packets to the sink is

Theoretical_Throughput(2) = $\frac{2*SC}{7*SD}$

For the case of Fig. 5.b, this delivery rate becomes

Theoretical_Throughput(3) = $\frac{3*SC}{10*SD}$

For an R-redundant LSN, this can be generalized by:

Theoretical_Throughput(R) = $\frac{R*SC}{((3*R+1)*SD)}$

Concerning $\frac{SC}{SD}$:

$\frac{SC}{SD}$ is common ratio independent of R, but depending on the value of parameters of physical and MAC layer used for the LSN. The implementation following this study will be based on the physical layer of 802.15.4, it is why this evaluation will be done using a bit rate of 250 Kbps. The throughput evaluation is based on 100 byte data-frames; the length of the data-frames has not a significant impact on throughput. The use of short frames reduces slightly the throughput introducing more overhead but it improves the end-to-end delay.

Simulations allow estimating the average time between the transmissions of two consecutive acknowledged frames. This time is useful to estimate the capacity of the shuttle that is to say the number of packets a node is able to send while being token holder. If each node is token holder during 250 ms (SD) and if transmitting period is 4.5 ms, the shuttle capacity (SC) is about 55 packets. So $\frac{SC}{SD}$ is equal to 44 kbps

Concerning $\frac{R}{3*R+1}$

$\frac{R}{3*R+1}$ is an increasing function. It starts at 0.25 and converges to 0.33. The optimum throughput obtained for a 3-redundant LSN is $\frac{12}{10}$ higher than that of a strictly linear network, so this function can be considered as a redundancy gain. This throughput increase has no impact on the FIFO size of the nodes. Traffic of a branch of such a network should be calculated so that the node of this branch that is neighbor of the sink contains at most SC packets when it becomes token holder. In this theoretical evaluation of the impact of factor R on the delivery packet ratio, the time needed for the token passing mechanism was neglected. This choice has no real impact if each node remains token holder in order to send a significant number of data frames. In the following is on this theoretical approach that simulations have been carried out. Simulation results confirm the expected gain in term of throughput.

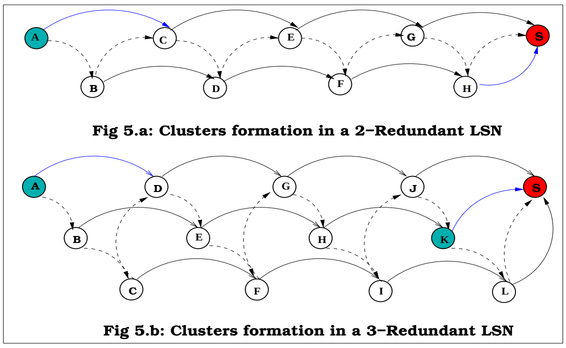

Figure 5: Clusters formation in LSNs.

6 EVALUATION

We perform our simulations on NS2 (version 2.32). Our results are given for a linear network of sixteen nodes: node 1 (the Allocator), is on the left side, and node 16 (the Sink), is on the right side. Local traffic is produced pseudo-periodically and starts randomly between 0 and 1 second, and independently for each node. A given current node might receive traffic to be forwarded when one of its neighbors becomes token holder. We suppose in the following that all the nodes of the LSN have the same type of queue managed in a first in first out (FIFO) manner. The capacity of this queue can be expressed by the number of packets (FiFoSize) it can contain. The existence of a channel for a downlink traffic is an interesting capability allowing the possibility of changing the period of token generation for example, but, in the following we suppose that the number of packets targeted to the sink represents the dominant traffic. The size of the reverse traffic is ignored in our simulations. The capture model is defined as in 802.15.4 and the new reception capture threshold is set to 10 dBm. The propagation model is Tworayground and we suppose also that all the packets have the same size. In this paper, we focus on the throughput as described above.

Table 1 presents the simulation parameters.

Fig. 6, Fig. 7 and Fig. 8 present the performances parameters in a 1-Redundant, 2-Redundant and 3-Redundant LSN in term of throughput in order to show the impact of the redundancy. They evaluate the evolution of the throughput as a function of data transmission rate for a given shuttle duration. For each shuttle duration, two phases can be identified: between 8 and 48 Kbps the throughput evolution increases. Indeed, in this phase, the load of the network is low and thus FIFO contain a few number of data packets for uplink traffic. The number of packets received by the sink from its direct neighbors per second is low. In this phase, nodes do not transmit any

Table 1: Simulation parameters.

Parameter	Value
Downlink traffic time	10 ms
Shuttle duration	[50-300]ms
Token packet size	11 bytes
Data packet size	100 bytes
Number of repetitions	50
Physical Layer	802.15.4
Transmission Power	-5 dBm
FiFoSize	60
Distance between two nodes in 1-Redundant LSN	90 meters
Distance between two nodes in 2-Redundant LSN	45 meters
Distance between two nodes in 3-Redundant LSN	30 meters
Data transmission rate	[8-80] Kbps

uplink traffic most of the shuttle duration. Between 48 and 80 Kbps the throughput evolution is stationary. During this phase the load of the network induces saturation. The FIFOs contain the maximal number of packets that can be sent during the shuttle duration. So, the number of packet received by the sink from its direct neighbor is constant. During this phase, nodes send uplink traffic most of the shuttle duration.

The impact of the redundancy can be shown also in Fig. 6, Fig. 7 and Fig. 8. Indeed, the throughput at the sink for each shuttle duration and for a given data transmission rate is higher for the 3-Redundant

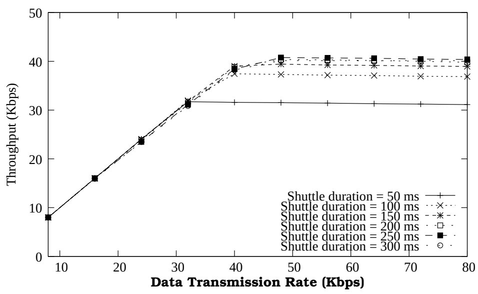

Figure 6: Throughput comparison by Shuttle duration in a 1-Redundant LSN.

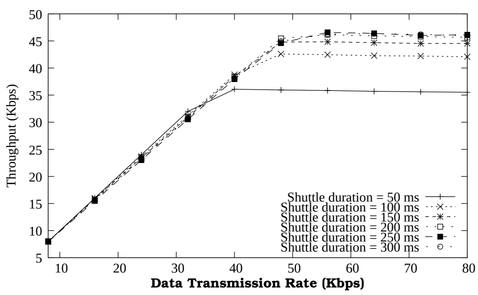

Figure 7: Throughput comparison by Shuttle duration in a 2-Redundant LSN.

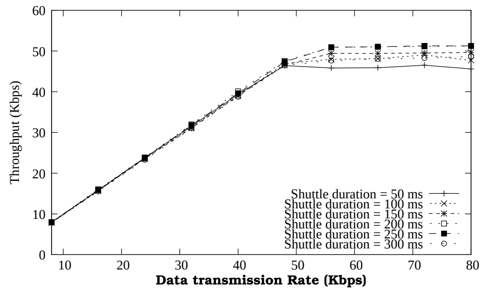

Figure 8: Throughput comparison by Shuttle duration in a 3-Redundant LSN.

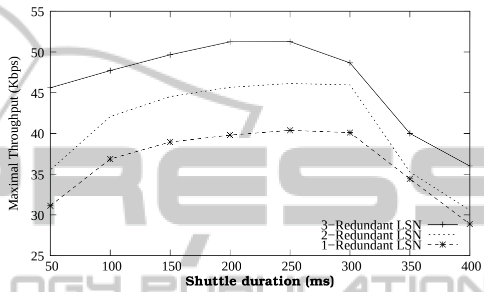

Figure 9: Maximal throughput for data transmission rate of 80 Kbps for various shuttle duration. The maximal throughput is achieved with a shuttle duration of 250 ms.

LSN and followed by the 2-Redundant LSN. For example for a shuttle = 50 ms, data transmission rate = 80 Kbps we have for3-Redundant: 45.5 Kbps, for 2-Redundand: 35.5 Kbp and for 1-Redundant: 31.1 Kbps. This confirms our theoretical analysis. Fig. 9 shows the maximal throughput for a data transmission rate of 80 Kbps for various values of the shuttle duration. This figure shows that maximal throughput is obtained for a shuttle duration of 250 ms. Indeed, direct neighbors from the sink transmit maximal number of packets from thier FIFO. Also, they are in the most time of the shuttle in transmitting state. Contrarily for the shuttle duration of 300 where nodes are more often in waiting state due to the fact that the FIFO are empty before the end of the shuttle. That is why the throughput decreases for a shuttle of 400 ms.

The impact of the redundancy can be shown. The maximal throughput is for the 3-Redundant LSN (traffic from 3 direct neighbors of the sink) is 51.27 Kbps , 46.13 Kbps for the 2-Redundant LSN and 40.37 Kbps for the 1-Redundant LSN.

7 DISCUSSION

The maximal throughput given by simulation is always slightly lower than the theoretical throughput. Some frames must be repeated on the path followed

Table 2: Throughput comparison between theoretical and simulation analysis.

R	Theoretical Throughput (Kbps)	Throughput from simulation (Kbps)
1	44	40.37
2	50.3	46.13
3	53	51.27

to reach the sink. This is decided after the expiration of the timer used to detect a no-acknowledgement. It is the main reason of this slight difference. Table 2 presents the comparison between theoretical and simulations results.

8 CONCLUSION

Linear Sensor Networks (LSNs) have a large interest for monitoring applications. In this paper , we propose a token based MAC protocol to manage the access to the medium. We study the behavior of LSN in the case of three topologies. Thus, we define a R-redundant LSN where R is the number of neighbors in each direction for a given node. Specifically, we study the impact of the redundancy on the throughput at the sink. We show that by theoretical and simulation analysis that more the factor of redundancy R is great more the throughput at the sink is also great. We show also that the redundant allows nodes to have an equitable distribution of the traffic by dividing the network into branches.

In future works, we plane to reverse channel in order to master the token production frequency according to the spatial reuse and energy saving constraints. Another way to improve the capacity of such a network is to add a priority policy to the node FIFO management by allowing highest priorities to the data frames coming from the farthest nodes. Finally, we plane to use a Log-normal Shadowing model in order to model the path loss due to the environment fluctuations.

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