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Improvement of Counter Based Broadcasting Scheme for Long Communicating Material Lifetime

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***Abstract*— The communicating material is a new paradigm of Internet of Things. It is designed to perform efficient product control and ensure an information continuum all along the product life cycle. Communicating material is obtained by scattering a huge amount of microelectronic components such as sensor nodes. However, a critical aspect of application with wireless sensor networks is nodes lifetime. The major part of energy consumption is caused by communication module, therefore judicious power management and scheduling can effectively extend operational time. In this paper, the counter based broadcasting scheme is focused on and a random delay extension is proposed to improve the wireless sensor network lifetime for communicating material application. The extension need neither additional hardware nor extra overhead, so that the strength of the original counter based algorithm is maintained. Simulation results using Castalia/OMNeT++ showed that our delay extension can reduce the number of retransmitting nodes by about 10% and hence improve the material lifetime compared with the original scheme.**

Keywords—wireless sensor network; communicating material; counter-based flooding; energy efficiency; network lifetime

I. INTRODUCTION

Recent advances in micro and nano sensors, integrated circuit technology and low-power wireless communications enable the deployment of extremely small, low-cost wireless sensor nodes. Applications of wireless sensor networks (WSN) with high density nodes distribution include remote environmental monitoring, smart spaces, military surveillance, precision agriculture, and communicating material [1] [2].

The communicating material is a new paradigm of industrial information system and it was presented and discussed for the first time in [3]. It enhances a classic material with the following capabilities: it can store data, communicate the information at any point of the product, and keep these previous properties after physical modification. This technology leads to an important change in intelligent product. Indeed, the material does not communicate using some tags or nodes in specific points, but becomes intrinsically and continuously communicating. To meet this vision, many ultra-small electronic devices (thousands) are scattered into the material of the product during its industrial manufacturing so as to be inseparable.

The first works focusing on communicating materials are presented in [4] [5]. It introduces a communicating material (e-textile) obtained by scattering a huge amount of RFID µtags (1500 tags/m²) in a manufactured textile. The system involves RFID reader/writer which is connected to a relational database that contains all the product life cycle information as shown in figure 1. At each writing operation, the database is explored to select the relevant data items that must be stored in the material. A Data item is a fragment of a database table, describing a particular data and requiring several bytes to be stored in the µtags when the textile passes under the writer module during the manufacturing phases. Since the RFID are memory-constrained, the data item is splitted (segmented) and stored over several tags using specific protocol header which is also able to rebuild the initial information.

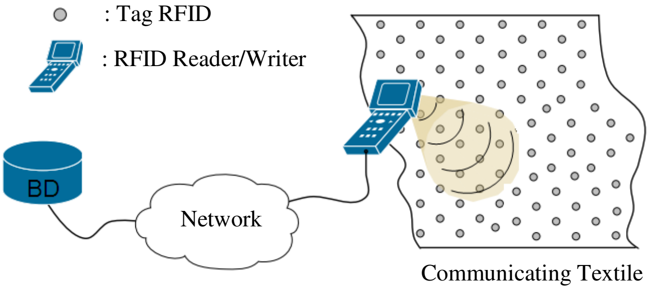

Fig. 1. Data storage system for communicating textile.

In a previous work [6], we have proposed to apply this system for solid and large materials such as concrete and wood using a multi-hop wireless sensor network technology as shown in figure 2. Ultra-small and micro-sensor nodes [7] [8] are dispersed into the material (100 nodes/m²). To store relevant data items in these scattered nodes, a dissemination algorithm is developed. It uses a counter named "Hop" which control the number of hops to do before storing the data. The packet is broadcasted from one node to all its neighbors, and at each hop the counter is decremented (Hop←Hop-1) until it reaches zero. In this case, the node must store the data, then resets Hop to its initial value, and rebroadcasts the packet within its neighborhood. This process continues until the edges of material are reached.

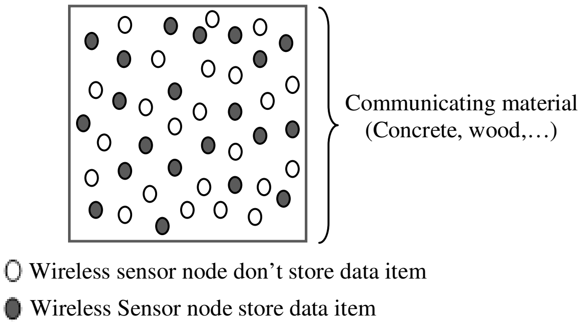

Fig. 2. Data storage in communicating material using micro-sensor nodes.

To broadcast the packet to all nodes of the material, the algorithm adopts a counter based forwarding scheme. When node receives the data packet, it fixes a random waiting delay. Then, it counts the number of retransmissions of the same packet by neighbor nodes. After the waiting delay has elapsed, the packet is only broadcasted if the number of retransmissions is smaller than a predetermined threshold.

However, the counter based forwarding scheme is resource blindness (i.e. node do not adopt energy saving scheme) [9]. Furthermore, the communicating material comprises multiple embedded ultra small wireless sensor nodes (thousands), each one uses very limited battery capacity and batteries replacement is impossible in such application. For these reasons, the energy consumption has to be optimized by reduction of the amount of transmitted data of each sensor node (i.e. wireless transmission consumes more energy than any other communication activity [10]).

The contribution of this paper is to improve the counter-based broadcasting scheme by controlling the random delay according to the remainder energy of wireless sensor node. In this paper, this improvement is called "random assessment delay extension".

The paper is organized as follow. The following three sections describe firstly the original counter-based scheme. Then, an improved counter-based scheme is proposed. Finally, the simulation results and the performance evaluation are presented. The last section concludes the paper.

II. BROADCASTING SCHEMES

Broadcasting (diffusing a message from a source node to all nodes in the network) plays an important role in multi-hop wireless sensor networks. It is usually used for routing path discovery (e.g. DSR and AODV), network reprogramming, fault tolerance, data mules, and mobile sink management [11]. Broadcast algorithms are usually referred to as flooding in which every node in the network retransmits an unseen received message once. However in dense sensor network, the flooding may cause serious redundancy, contentions and collisions which leads to high overheads and high energy consumption [12]. To solve these problems, various efficient broadcast schemes have been proposed as shown in table 1. These schemes are usually divided into two categories [13] [14]: *deterministic* and *probabilistic*. Deterministic schemes require global/local topology information of the network for rebroadcast decision. On the other hand, probabilistic one does not require this information as every node is allowed to retransmit a message based on a predetermined forwarding probability.

TABLE I. BROADCASTING SCHEMES

Probabilistic schemes	- Probabilistic-based [15] - Counter-based [16]
Deterministic schemes	- Distance-based [17] - Location-based [18] - Cluster-based [19] - Neighbor-knowledge-based [20]

Distance and location-based schemes exploit distance between nodes and their positions information, respectively. Such information is useful to reduce the amount of rebroadcasting. Nodes, however, need to be equipped with a Received Signal Strength Indicator (RSSI) or a Global Positioning System (GPS). Such additional functions increase the cost of nodes.

Neighbor-knowledge-based methods require that nodes exchange *hello* packets periodically to get the neighbors information. According to this information, the nodes can suppress unnecessary broadcasts. However, *hello* packet exchange incurs a large amount of communication overheads and energy consumption.

With cluster-based, the network is divided into groups of nodes. Such scheme require cluster formation phase using specific algorithms which incurs more energy consumption and overhead.

Probabilistic-based scheme define a value *P*. On receiving a forwarded message, node will rebroadcast it with a probability *P*. The scheme reduces more redundancy, contention and collision using small value of *P*. A random delay is inserted before rebroadcasting the message to differentiate the timing of transmission between neighboring nodes.

Counter-based scheme uses different method to reduce redundancy and contention. When node receives a new packet, it fixes a random waiting delay before making the forwarding decision. During this delay, the sensor counts the number of retransmissions of the same packet by neighbor nodes. After the waiting delay has elapsed, the packet is only forwarded if the number of retransmissions is smaller than a predetermined threshold. As a result, the forwarding ratio depends on the nodes density. In low density areas this ratio will be high, whereas in high density areas it will be low.

Probabilistic and counter-based schemes reduce the amount of unnecessary rebroadcasts. This is achieved without additional hardware and without any control messages. Such features are desirable for micro-sensors networks and specially communicating material application because the cost of nodes can be reduced and energy resources can be saved. However, authors in [21] [22] show that counter-based scheme outperforms the probabilistic one in terms of reachability (i.e. the percentage of nodes that are reached on average) and efficiency (i.e. the average amount of resources required for broadcasting a message). For this reason, the counter-based can be regarded as a promising broadcast algorithm for dense wireless micro-sensor networks and communicating material applications.

III. COUNTER-BASED BROADCASTING SCHEME

In simple flooding, the more duplicate broadcasted packets a node receives, the less effective its rebroadcasting becomes [23]. This is because the duplicate messages are likely to have been received by its neighboring nodes. This fact is involved in the counter-based flooding. In this scheme, a node that has received redundant packet more than a predefined threshold *Cth* cancels the rebroadcasting. The counter-based algorithm is shown below:

1) When a node receives a broadcasted packet for the first time, the node initializes a counter *N* to one, and sets a random assessment delay (RAD) at a value between 0 and T_{max}.

2) If the node receives the same broadcasted packet during the RAD, it increments the counter *N* ($N \leftarrow N+1$). If the counter reaches a preset threshold *Cth*, it cancels the rebroadcasting.

3) After the RAD expires, the node rebroadcast the packet to all neighbors.

Figure 3 summarize the algorithm of this scheme in each node.

```
Algorithm: Counter-Based Broadcasting Scheme
For a node X
Upon reception of a broadcasted packet m for the first time
    - Initialize the packet counter N to 1
    - Set and wait for RAD to expire
    - While waiting:
            o For every duplicate packet m received
            o Increment N by 1
    - When the delay RAD expires
    - If (N<Cth)
            o Retransmit the packet m
    - Else
            o Drop the packet m
End Algorithm
```

Fig. 3. Algorithm of the counter-based broadcasting scheme

Increasing *Cth* gives a better reachability, but also reduces the benefits of counter-based algorithm (i.e. many retransmitting nodes) [24]. The theoretical results in [25] suggest that *Cth* should be 4 or less for good performance in typical networks. Authors in [26] show that a threshold *Cth* set between 4 to 6 is preferable from the viewpoint of the trade-off between reachability and efficiency. Furthermore, simulation results in [27] (presented first in [28]) show that if the threshold is set to 4, the reachability is over 99.5%.

In [24], the scheme is tested in a real wireless multi-hop network using t-mote Sky (based on Telos Revision B) from Moteiv Corporation, which is a sensor mote platform for extremely low power and high data-rate wireless sensor network applications. Authors showed that a threshold of 2 causes the reachability to suffer, while a value of more than 3 does not improve much. Instead, it only increases the number of retransmissions. They showed also that as T_{max} became smaller, the retransmissions increased. And, when the RAD is 200 ms, there is very little improvement in the retransmissions if further increased. Using *Cth*=3 and T_{max}=200 ms, the reachability was extremely good in dense sensor network scenario.

There are some research efforts to optimize and reduce the number of retransmitting nodes, hence improve the network lifetime for counter-based scheme (i.e. the major part of energy consumption is caused by communication module). In [29], a node sets the value of the counter threshold *Cth* according to the number of its neighboring nodes (i.e. the local density). In [26], a node sets *Cth* according to the distance from the broadcasting node to itself. Similarly, in [30] and [31], the RAD is a function of the distance from the broadcasting node. Moreover, author in [14] extend the scheme by adapting the RAD value to network congestion (i.e. different RAD values are used for each rate of packet reception).

These extensions, however, use network topology, neighborhood awareness, distance and location information to improve the scheme. Such improvements possibly diminish the strength of the original counter-based scheme (i.e. no additional hardware and low overhead). Furthermore, they don't assume the remainder energy level of nodes which could lead to the loss of important located nodes. This problem is the key contribution of our work.

In this current paper, the remainder energy is processed. The nodes with low energy level have to wait for large random delay RAD than others. So, they are prevented from rebroadcasting and hence improve their lifetime as much as possible. The counter-based broadcasting scheme has to maintain high reachability using our extension.

IV. PROPOSAL RANDM ASSESSMENT DELAY EXTENSION

The random waiting delay is processed in this paper to prevent as much as possible the nodes with low energy level from rebroadcasting. As consequence, the rate of rebroadcasting of each node is adapted to their remaining energy. In the original counter-based scheme, node selects random waiting delay RAD between 0 and a fixed period of time T_{max}. To adopt this mechanism to remaining energy level of node, the equation 1 and 2 are developed.

$$RAD_{extension} = RAD \times K \qquad (1)$$

$$K = (E_{initial} / E_{remainder}) \qquad (2)$$

$RAD_{extension}$: random assessment delay extension.

$E_{initial}$: initial energy of sensor node.

$E_{remainder}$: remainder energy of sensor node.

RAD is multiplied by *K* which increases the waiting delay when the remainder energy becomes lower as shown in figure 4.

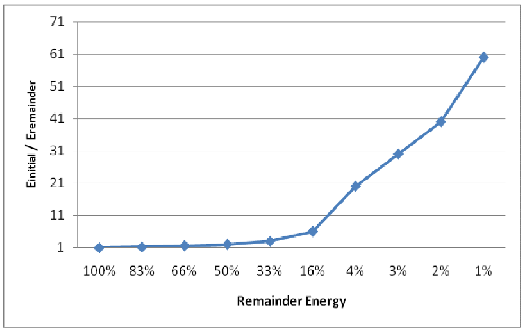

Fig. 4. Remainder energy versus the fraction $E_{initial} / E_{remainder}$.

If the remainder energy is very low, the waiting delay $RAD_{extension}$ is larger. So, the node has to wait more than others and count the number of retransmission *N* of neighbor nodes which have more energy. As consequence, it has more chance to reach the counter threshold *Cth* and cancel the rebroadcast which conserve more theirs energy.

V. SIMULATION AND PERFORMANCE EVALUATION

In this section, the simulation setup is described firstly. Then, the simulation results are presented and discussed.

A. Simulation setup

The performance of our solution is evaluated through simulation. Castalia simulator is used to implement the improved counter-based broadcasting scheme. Currently, many wireless sensor network simulators are available as COOJA and TOSSIM but Castalia provides realistic wireless channel, radio models and node behavior [32].

In particular, Castalia has been configured to support communicating material application. A specific radio module is developed which is consistent with CC2420 components but allow more reduced transmission range. Thus, a thousand of scratted nodes in small material size could be simulated. The chosen simulation parameters are summarized in table 2.

TABLE II. SIMULATION PARAMETERS

Material size	5m x 5m
Number of nodes	2500
Nodes density	100 nodes/m²
Nodes distribution	Grid 50x50
Location of source node	Center of the material
MAC layer	TMAC
Transmission power	-90 dbm
Radio	CC2420
Radio Collision Model	Additive interference model

B. Simulation results

1) Reachability and retransmitting nodes performances

In this section, the number of reached nodes (reachability) and the number of retransmitting nodes are used as performance metrics for the evaluation of our extended counter-based broadcasting scheme.

In order to verify the effect of our extension, simulation comparisons between the original scheme and the proposed one is performed. Different energy levels (Low $E_{remainder}$, Medium $E_{remainder}$, and High $E_{remainder}$) are randomly affected to sensors nodes in the material.

The counter-based scheme has two control parameters: *Cth* and T_{max}.

First, T_{max} is set to 10 second and the counter threshold *Cth* is varied. For each threshold, 30 trials with different random selection of RAD are executed and the average values of them are plotted in figures 5 and 6 for number of reached nodes and number of retransmitting nodes, respectively.

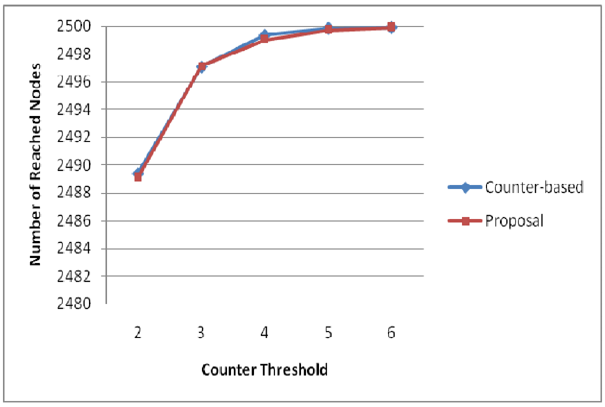

Fig. 5. Counter threshold versus number of reached nodes.

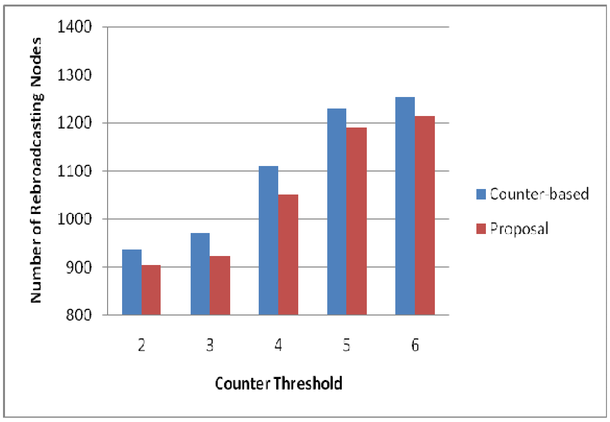

Fig. 6. Counter threshold versus number of retransmitting nodes.

As shown in figure 5, there is no difference in number of reached nodes. The reachability is over 99% for all counter thresholds. However, figure 6 shows that our proposed scheme reduces the number of retransmitting node by 10% because low energy level nodes don't rebroadcast packets. They have more waiting delay to count the retransmission of neighbor nodes (i.e. neighbors that have further residual energy) and have then more chance to reach the counter threshold and cancel rebroadcast.

The larger counter threshold, the more retransmitting nodes and hence the more energy consumption. In the rest of the paper, *Cth* is set to 4.

Next, the value of T_{max} is varied. For each value, 30 trials with different random selection of RAD are also executed and the average values of them are plotted in figure 7 and 8.

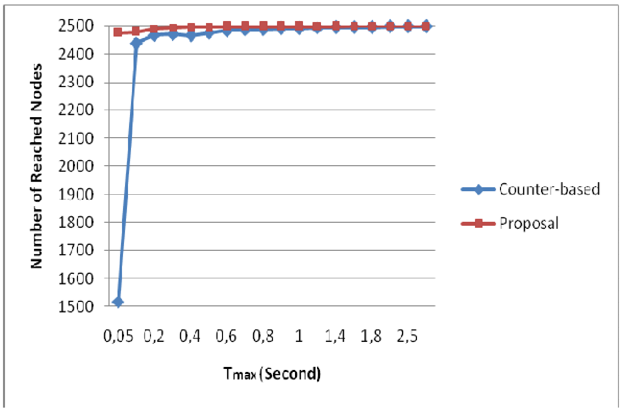

Fig. 7. T_{max} versus number of reached nodes.

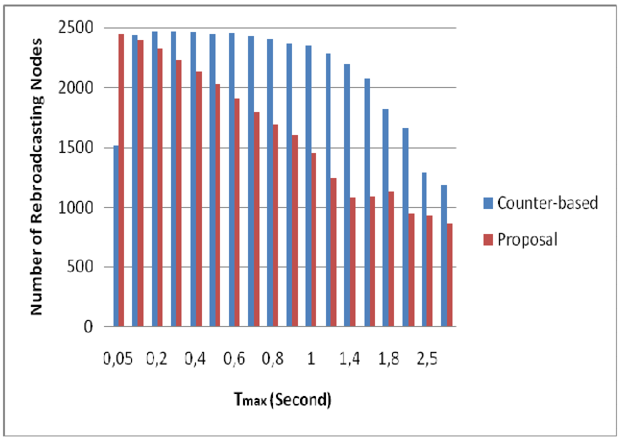

Fig. 8. T_{max} versus number of retransmitting nodes.

As shown in figure 7, the reachability is not influenced by T_{max} for our proposed scheme. However, the number of reached nodes of the original counter-based drops in the case of too small T_{max} (100 ms or less). This is because the broadcasted packets are transmitted by nodes during a short period, so they tend to collide each other and data don't reach a part of the communicating material. That is why also the number of retransmitting nodes drops in case of 50 ms of the original counter-based in figure 8.

The number of retransmitting nodes is significantly reduced with our scheme as the low energy level nodes doesn't retransmit packets as much as possible which optimize and balance the energy consumption of ultra-small nodes in the material. As consequence, the proposed solution outperforms the original counter-based in collision avoidance and energy consumption balance.

The longer T_{max}, the less retransmitting nodes (less energy consumption) but the larger broadcasting delay in the communicating material. T_{max} is set to 700 ms in the rest of the simulation study.

2) *Energy consumption performance*

In this study, all nodes have an initial energy equal to 18760 J. Broadcasting of different packets is simulated in the communicating material until the end of network lifetime. The average of consumed energy by all nodes is measured in different periods of time. The simulation result of the proposal and the original counter-based scheme are shown in figure 9.

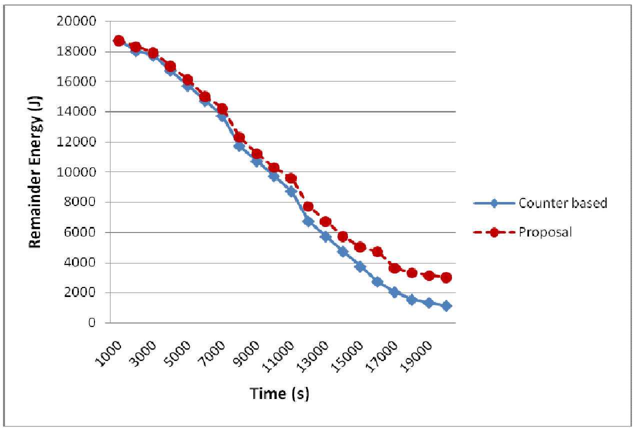

Fig. 9. Counter threshold versus number of retransmitting nodes.

Figure 9 shows that there is no difference between the proposed and the original scheme in the beginning of network lifetime. However more time passes, our solution shows more energy conservation as nodes have different remainder energy and the lowest ones are not involved in broadcasting as much as possible. So, the random delay extension keeps a lot of energy and gives an equitable use of nodes resources (energy balance).

Therefore, our solution optimizes more the energy consumption and ensures a long communicating material lifetime (i.e. network lifetime) than the original counter-based scheme.

VI. CONCLUSION

In this paper, the counter-based scheme is focused on as a broadcast algorithm for communicating material using wireless sensor networks, and a random delay extension has been proposed to improve the original. The remainder energy level is processed to prevent as much as possible the nodes with low energy level from rebroadcasting which conserve more theirs resource. The performance of this solution is evaluated through computer simulation using Castalia/OMNeT++. Simulation results showed that our delay extension maintain the high reachability of the original scheme. However, it enhances the communicating material lifetime and reduces the number of retransmitting nodes by about 10%. The proposed extension can be applicable for any other broadcast algorithm which uses the random waiting delay.

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