Efficient retransmission algorithm for ensuring packet delivery to sleeping destination node

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Abstract The routing protocol plays a key role in allowing packets to reach their intended destination. We are interested in wireless nanonetworks (WNNs), which totally differ from traditional wireless networks in terms of node density and size, routing protocol used, and hardware limitations. This paper presents an enhanced retransmission algorithm used by the nodes in the destination zone, in combination with our previously proposed nanosleeping mechanism. This algorithm increases the chance of a destination node to capture the intended packet, while decreasing the number of participating nodes in the retransmission process. We evaluate the enhanced retransmission algorithm and show its effectiveness in reducing node resource usage while maintaining a high packet delivery to the destination node.

1 Introduction

Recent trends in telecommunication tend to promote work in wireless networks. This is due to several reasons, the most important of which is the easier installation and higher scalability compared to wired networks. Wireless networks include many

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types (Wi-Fi, Bluetooth, mobile communication 2G, 3G, 4G etc.) In the current paper we focus on *nanonetwork* communication paradigm.

Nanotechnologies promise new solutions for several applications in biomedical, industrial, and military fields [1]. Nanonetworks are built from tiny nodes, equipped with computing, sensing, and actuating devices. They usually have a small CPU, small memory, and low battery. The interconnection of nanonodes would expand the hardware capability of a single nanonode, and allow them to cooperate and share information. Those networks use electromagnetic waves in the THz band (0.1–10 THz) for their communications [3]. Due to the small communication range and power constraints, they need to use multi-hop communications to cover large areas.

Traditional communication technologies are not suitable for nanonetworks mainly because of the density, size and power consumption of transceivers and other components [6]. We have some knowledge about the main hardware components that constitute a nanodevice, and about network architecture [7].

To ensure that packets reach their destination, a routing protocol is required. Nanonetworks impose more constraints to it, and the routing protocol must take into consideration the nanoscale communication's characteristics. Traditional routing protocols are not adequate for wireless nanonetworks. Differences are in terms of bandwidth, energy, and node processing capability. Designing a routing protocol becomes a challenge in WNNs due to resource constraints on data processing, memory, and energy. While designing new routing protocols, the following points must be considered:

- *Energy efficiency*: Nanonodes are battery-powered. In low dense environments, and where there is a high rate of data exchanging, energy shortage is a major issue. Therefore, the routing protocol should be energy efficient [2].
- *Scalability*: Nanonetworks could be of different densities (low, medium, high, ultra-high, where nodes have numerous neighbours). Therefore, the routing protocol must support various network densities.
- *Complexity*: Due to limited hardware capability and resources, the complexity of a routing protocol may affect the performance of the entire WNN. The lower the complexity, the highest its effectiveness.
- *Delay*: In some applications, the delay, defined as the time taken to transmit the data from the source node to the destination node, is a key factor in message receiving or response. Therefore, the routing protocol should provide a reasonable delay.

SLR (Stateless Linear-path Routing) [8] is the protocol we use in our evaluation. It implements a coordinate-based routing, in which data packets are routed in a linear routing path. Nodes are assumed to be placed in a cubic space, distributed in zones. In the initial SLR phase, during network deployment, a few anchor nodes broadcast a packet (beacon) to the whole network. The hop counter in those beacons is used to define the coordinates of all nodes as a distance to the anchors. In the second phase, during data packet routing, nodes choose to forward a packet if and only if they are on the path between the source and the destination, based on the coordinates defined in the initial phase.

SLR protocol uses the TS-OOK (Time Spread On-Off Keying) modulation [9] to share the radio terahertz channel to nanodevices. Unlike traditional carrier-based network technologies, TS-OOK is pulse-based and consumes less energy. It is based on femtosecond-long pulses where packets are transmitted as a sequence of pulses interleaved by a given duration, cf. Fig. 1. "1" bits are encoded with a power pulse of duration T_p, and "0" bits are encoded as silence. Because sending consecutive pulses needs unavailable hardware and power at such small sizes, consecutive bits are spaced with a duration T_s which is usually much longer than the pulses themselves.

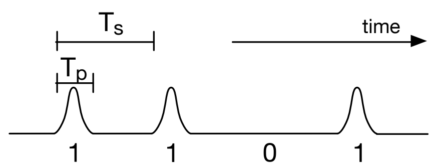


Fig. 1: TS-OOK pulse-based modulation.

In order to consume less resources (energy, memory etc.), a traditional mechanism is to make nodes sleep. However, in this case it might happen that the destination node be asleep when a packet arrives to it and its (destination) zone. To allow the destination node still receive the packet, one method is to make nodes at the destination zone retransmit the packet.

This paper presents an enhanced retransmission algorithm used by the nodes in the destination zone. This algorithm increases the chance of a destination node to capture the intended packet, while decreasing the number of participating nodes in the retransmission process.

The article is organized as follows. Section 2 presents the Related work, and Section 3 presents the Background. The probabilistic retransmission algorithm we propose is detailed in Section IV, and Section V evaluates it through simulations. Finally, section VI draws the conclusions.

2 Related Work

Several routing protocols have been proposed for sensor, ad hoc, and similar types of networks. Nanonetworks differ from those by:

- The limited processing power and memory available.
- The massive number of neighbors a node can have (thousands or even millions).
- The unavailability of node positioning mechanisms.
- The ability to multiplex many frames over the same period of time.

- The energy harvesting from the environment. This will lead to preserving nodes' resources and increasing network lifetime.

2.1 Pure flooding

In ad-hoc wireless networks, multi-hop data broadcasting is an essential service. It is required by several applications, and used to broadcast information in the network (e.g. routing table updates, path updates, etc.)

Pure flooding is one of the traditional routing methods that has proven its performance in terms of delivery ratio, and delay in many always-awake network settings [11]. It is motivated due to its simplicity, which conforms to the constraint capabilities of the nanonodes.

Flooding is important especially in mobile ad-hoc networks (MANETs), which rely on it to perform routing discovery. It is an unreliable operation with no acknowledgment mechanism in place. In pure flooding, a node forwards each message (*without routing data*) received for the first time. However, this technique has drawbacks, the most notable is the generation of a significant amount of messages in the whole network. In dense networks, exponential propagation growth leads to a broadcast storm. Moreover, countermeasures have to be taken to prevent skyrocketing contention for channel access or collisions.

We argue, however, that these solutions suffer severe performance degradation (in both energy and time efficiency) if directly applied to low duty-cycle networks. It is very costly when energy consumption is considered.

2.2 Probabilistic flooding

Many attempts have been made to optimize the pure flooding technique by selecting a subset of forwarding nodes. They are challenged by nanonode hardware limitation, either by the inability to build a complete map of even the direct neighbors, or because of too high memory requirements.

A common solution is to give each node a probability to forward a new packet (already seen packets by a node are discarded anyway.) The probability chosen could be fixed, or depend on several factors, such as density, distance, speed, and others. The most considered metric in calculating the probability is the number of neighboring nodes.

Probabilistic flooding greatly reduces redundant retransmissions and receptions compared to the pure flooding scheme. Several probabilistic flooding schemes have been proposed for wireless ad-hoc networks that require lightweight computing resources. Hence, they can be used for data dissemination in nanonetworks [12]. One of the most important defects they have is the die-out problem [14].

3 Background

3.1 Sleeping mechanism

In networks where nodes have limited energy, the common technique to preserve energy is the duty cycling (sleeping). Nodes wake up from time to time to receive packets sent to them. Sleeping techniques used in the traditional networks are not adequate for nanonetworks due to communication peculiarities (pulse-based).

In our proposed fine-grained sleeping mechanism [10], all the nodes have the same awake-sleep cycle, equal to T_s. Inside the cycle, all the nodes have the same awake *duration* (or percentage of T_s), but the *beginning* of the awake interval is different for each node and is randomly determined. For this to work, all the flows must have the same spreading ratio $\beta = T_s/T_p$.

The normal purpose of a communication process is to deliver information to a destination. The definition of destination (zone or node) may change depending on the application. If the destination is defined as an SLR address (*zone*), this means that the packet should reach this SLR zone and at least one node must receive it (it does not matter which one). In that case, the mechanism we proposed in [10] is efficient.

However, if the packet needs to reach a specific node in the destination zone, then more aspects have to be taken into consideration. When a packet arrives at the destination zone, the destination node may indeed be asleep and would miss the packet.

For additional information about the nanosleeping mechanism, refer to [10].

3.2 Full retransmission algorithm

Nanonetwork applications can vary from biomedical (e.g. drug delivery) to agricultural (e.g. water and pesticide monitoring) and environmental (e.g. air pollution control) services. Nanonodes can be implanted into the environment, food, or the human body. Therefore, and in some particular applications, it is extremely important for the destination node to receive all the data.

To the best of our knowledge there has been no research in the literature on customizing a method to ensure that the packet reaches a sleeping destination node. For that reason, a retransmission algorithm was already proposed [5] in combination with the sleeping mechanism. The aim of this algorithm is to increase the destination node's chances of receiving the packet if it is asleep when the packet reaches the destination zone. It is worth mentioning that the algorithm is used only by the nodes at the destination zone.

In the absence of the retransmission algorithm, the destination node does not receive the packet if it was in sleep mode when that packet arrived at the destination zone.

Deep analysis for the retransmission behavior at the destination zone shows that after a segment of time all the nodes will participate in retransmitting the packet. For example, in a destination zone of 41 nodes, there are 41 retransmission attempts. This will lead to an increase in packet exchanging, therefore a waste of nodes' resources, and the occurrence of congestion phenomena. An enhancement to this algorithm is needed, without affecting the node's reception reliability.

The objective of this paper is to present such an enhancement.

4 Probabilistic retransmission algorithm

To the best of our knowledge, there is no similar proposed algorithm that takes into consideration achieving a reliable packet reception at the destination (zone/node).

In some applications, ensuring a reliable packet reception by a specific node is a key factor. For example, periodic car maintenance can be explained as a service/maintenance model, where a car undergoes a service/maintenance either after a certain specified time period or on the basis of a part getting faulty [16]. Car parts (brake, motor, etc...) are equipped with a sensor for monitoring and data collecting purposes. For some reason, if the brake sensor does not receive or collect information, this might put the driver at risk in case the brakes are faulty. Therefore, having a packet reception algorithm of high reliability becames a key factor in IoT applications.

Allowing all nodes at the destination zone to retransmit the packet leads to nodes' resources being exhausted. To avoid this problem, we propose a probabilistic retransmission algorithm, where not all the nodes participate in the retransmission mechanism. The number of participating nodes is determined based on a probability, calculated as follows:

$$probability = 1 - \frac{aD}{T_s} \tag{1}$$

In this formula, the retransmission probability is inversely proportional to the awaken duration percentage *aD*. Table 1 shows the expected number of participating nodes among various awaken durations.

No matter the network density, this algorithm never saturates the radio channel and does not require much memory, or computations. The only memory needed is the buffer to store the received packet to retransmit it at the end of the awaken duration.

In this algorithm, we took into consideration the case where the awaken duration spans over two time cycles. The variables used in the algorithms are the following:

- *waitingTime*: node waiting time before packet retransmission at the end of its awaken duration.
- *wT1ts*: node waiting time if the awaken duration range is 1 T_s.
- *wT2ts*: node waiting time when its awaken duration spans on 2 T_s.
- *aD*: node awaken duration.

Table 1: The expected number of participated nodes in full and probabilistic retransmissions.

Awaken duration (%)	Full retransmission	Probabilistic retransmission
6	35	35–38
10	41	34–37
20	41	32–35
30	41	28–32
40	41	25–28
50	41	21–25
60	41	15–21
70	41	11–15
80	41	7–11
90	41	3–7
100	41	0

- *aS*: node awaken starting time.
- *pcktrecp*: the time when the node receives the packet.
- *probaRNG*: a probability random number generator function (0,1).
- *proba*: the calculated probability based on node awakenDuration.

The node retransmits the packet if and only if the *probaRNG* random variable is less than the calculated probability. The enhanced packet retransmission algorithm is presented in Algorithm 1.

Algorithm 1 Probabilistic retransmission algorithm executed by nodes at the destination zone only.

alreadyseen = false
waiting$T$ime
wT1ts = (aD - (pcktrecp - aS)) % T_s
wT2ts = - (aD - (pcktrecp - aS)) % T_s
if packet type is data **then**
    if packet !alreadyseen AND the received node is not the destination node **then**
        alreadyseen = true
        if pcktrecp % $T_s \geq$ aS **then**
            waiting$T$ime = wT1ts
        else // pcktrecp % $T_s <$ aS + aD - T_s
            waiting$T$ime = wT2ts
        end if
        probaRNG = rand (0, 1)
        proba = 1 – (aD / T_s)
        if probaRNG < proba **then**
            the node will retransmit the packet at the end of its aD (now + waiting$T$ime)
        end if
    end if
end if

5 Evaluation

This section evaluates the retransmission algorithm in improving packet reception reliability at the destination zone. As a detailed analytic study is not possible and nanomachines have not yet been manufactured, we evaluate the protocol through simulations. Technical details and information about the full reproducibility of our results are provided on a separate website[1].

We use BitSimulator[2] [4] to evaluate our proposed ideas. BitSimulator allows to simulate ultra-dense nanonetworks using TS-OOK modulation. It simulates applications and routing protocols while keeping a relatively detailed model for the MAC and physical layers. As such, it enables exploration and understanding of the effects of low level coding and channel access contention. It comes with a visualization program, VisualTracer, which displays graphically the simulation events, such as in Fig. 2.

In our simulations, the network topology consists of a homogeneous network as a 2D area of size 6 mm * 6 mm, cf. Table 2. One packet traverses the network; the source node is at the bottom left of the network, while the destination node is at the top right, cf. Fig. 2.

Parameter	Value
Size of simulated network	6 mm * 6 mm
Number of nodes	25 000
Communication radius	500 µm
Hops to reach the furthest node	17
AwakenDuration	6000 fs
T_p	100 fs
β (spreading ratio)	1000
Packet size	1000 bit

Table 2: Simulation parameters.

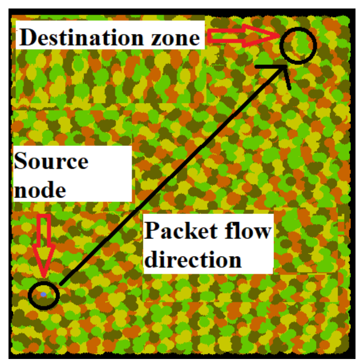


Fig. 2: The evaluated network.

In the following analysis, all the nodes use the sleeping mechanism. The simulation is repeated several times by changing the node awaken duration percentage, all the other parameters being kept identical.

The metrics used to analyze the algorithm efficiency are the number of nodes that retransmit the packet at the destination zone, and the reliability of receiving at least 1 copy of the packet by the destination node.

Determining a static awaken percentage for every node in the network (e.g. 20% is equivalent to 20 000 fs) means that all nodes will be awake for this percentage in a time duration equal to T_s. We recall that inside this cycle, all the nodes have

[1] http://eugen.dedu.free.fr/bitsimulator/aina22

[2] Free software, available at http://eugen.dedu.free.fr/bitsimulator

the same awaken duration (or a percentage of T_s), but the beginning of the awake interval is different for each node and is randomly determined.

The probabilistic retransmission algorithm aims to decrease the number of participating nodes in packet retransmission at the destination zone. Fig. 3 shows the efficiency of this algorithm compared to the full retransmission. We notice that for an awaken duration of 6%, both transmissions mechanisms have the same number of participating nodes (35). This is expected since for a low awaken duration the probability of retransmission is high.

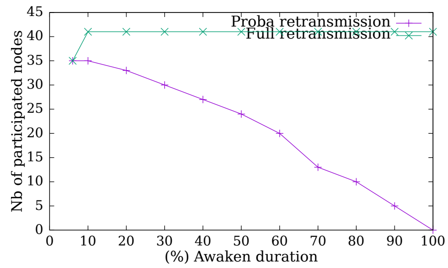


Fig. 3: Participating nodes in packet retransmission at the destination zone.

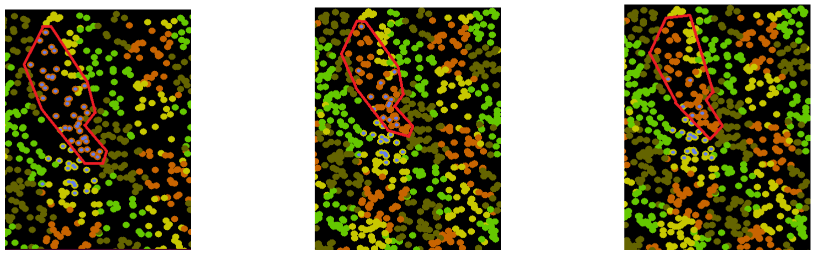
The relation between the awaken duration and the probability is inversely proportional. While the awaken duration increases, the probability decreases, therefore it reflects a decrease in the number of participating nodes while using the probabilistic retransmission algorithm. For example, for an awaken duration of 50%, the number of participating nodes is 25 with the proba algorithm, while with the full retransmission this number remains steady, 41 nodes, for all the simulated awaken duration (recall that the total number of nodes at the destination zone is 41).

Fig. 4 is a sketch extracted from VisualTracer. The figure shows the benefit of applying the probabilistic retransmission against the full retransmission. (a) Shows that all nodes (41) participate in retransmission at the destination zone. Applying the proba retransmission in (b) while using the same awaken nodes percentage, shows a decrease of 68% of participating nodes. An increase in the awaken duration percentage (c) shows a higher decrease in the number of participating nodes (88%) compared to the full retransmission.

It is important to ensure that the algorithm does not affect packet routing in the previous zones. Fig. 5a shows that the number of participating nodes in the packet routing does not change while applying the retransmission algorithm. Therefore, the previous zone is just playing the role of routing the packet and sending it to the next hop (*zone*).

Fig. 5b shows the reliability of packet receiving by the destination node. In all simulations, and using several awaken duration percentages, the destination node is still able to receive at least 1 copy of the intended packet.

Using several flows in a network might affect the algorithm being applied. For that reason, it is necessary to evaluate our algorithm when using several flows too.

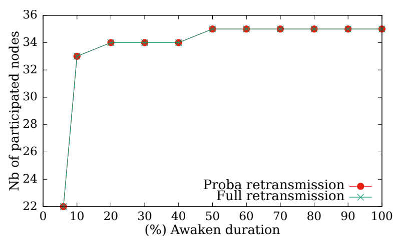


(a) Full retransmission, all nodes paticipating at the destination zone.

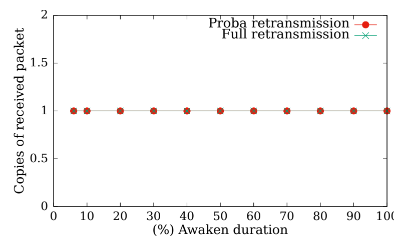
(b) Proba retransmission applied for 70% of node awaken duration.

(c) Proba retransmission applied for 90% of node awaken duration.

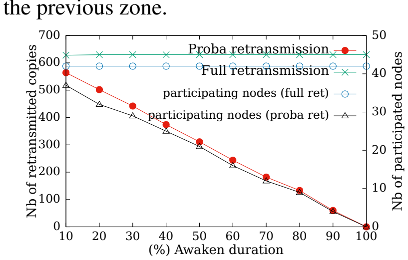
Fig. 4: VisualTracer sketch for the destination zone, for the number of participated nodes with full and proba packet retransmission.



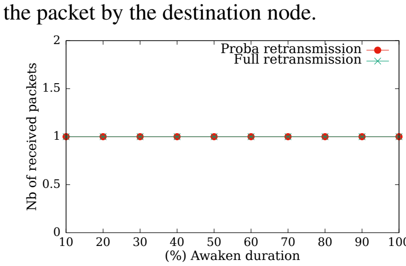
(a) Retransmission mechanism does not affect the previous zone.



(b) The reliability of receiving at least 1 copy of the packet by the destination node.



(c) Number of retransmitted packet copies and nodes handling.



(d) The destination node success to receive at least 1 packet copy of each flow.

Fig. 5: Probabilistic retransmission simulations results.

Fig. 5c depicts the results of a simulation with 15 flows from 15 source nodes sending packets to one destination node. For full retransmission, the number of retransmitted packet copies (≈620) stays stable along all the awaken duration percentages used. Even if this number decreases, it achieves around 50% fewer retransmissions (≈310) at 50% of node awaken duration, and 11% fewer retransmissions at 90% of awaken duration.

This is also reflected in the number of participating nodes, where all the nodes (42 nodes) are participating in the full retransmission. This number decreases according to the awaken duration percentage used in the proba retransmission (e.g. 20 nodes at 50% of awaken duration, and 5 nodes at 90% of awaken duration).

Fig. 5d shows that the use of the probabilistic retransmission algorithm contributes to enhancing packet reception reliability: the destination node receives at least 1 copy of the retransmitted packet from each flow. Once again, the probabilistic algorithm proves its effectiveness even in case of several flows.

6 Conclusion

In this paper, we proposed and discussed a probabilistic retransmission algorithm at the destination zone where not all nodes participate in retransmission process. The goal is to ensure that the destination node receives the packet, while reducing the number of packets exchanged. In the proposed algorithm, the number of participating nodes is correlated to the percentage of nodes awaken duration.

The evaluations show that probabilistically retransmiting the packet at the destination zone ensures high reliability in packet reception. Therefore, the benefit from this algorithm can significantly vary from one application to another. The simulation results show that the destination node is still able to receive the intended packet while decreasing the number of retransmissions at the destination zone.

Besides the probabilistic retransmission, using the sleeping mechanism improves network behavior by limiting the amount of traffic an individual node can see. Traffic is statistically dispatched over all nodes, thus sharing the load. As individual nodes see less activity, they also use fewer resources (energy, CPU, memory), therefore the network lifetime will increase.

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