Impact of Routing Protocols on Packet Retransmission over WSNs

Thibault Bernard, Hacène Fouchal, Sébastien Linck and Estelle Perrin
CReSTIC Lab
Université de Reims Champagne-Ardenne, France

***Abstract*—TCP is known to exhibit poor performance in Over wireless networks. Various parameters may be considered to configure the network functioning with multi-hop wireless connectivity. Many routing protocols could be used over WSN.**

In this paper, we show that the choice of the routing protocol (and its parameters) will surely have an impact on the whole network functioning. We focus, in particular, on packet retransmission process which is an usual process used by a node when the network is disturbed (traffic jam, non connected nodes, ...) However, multi-hop end-to-end transmissions require cooperation of several layers of the communication protocol stack. At each layer different mechanisms and protocols are used, each of them are set default values. In this paper, we investigate how these layers are designed and we consider taking a look at default configurations of the layers parameters/mechanisms and comparing them to alternative possibilities. We also explore cross-layer effects between layers and how they affect the performance. We analyze the impact of usual routing protocols such as Direct Diffusion, AODV, AOMDV, DSDV and DSR on the packet retransmission used by the transport layer. These analysis are conducted through the NS-2 simulator to enhance two relevant indicators: the CWL value and the MAC retries ratio.

Keywords: Wireless network, MAC protocols, Routing protocols, TCP, Cross-layer, 801.15.4.

I. Introduction

Wireless sensor networks (WSNs) are a widely used technology in particular for monitoring various environments. WSNs are composed of small wireless devices (sensors) connected to transducers. In general, WSNs are dedicated for monitoring physical environment and collecting data from it. They are used in various domains [**?**] such as ground monitoring, patient monitoring, animal monitoring,... Thus, many works deal with WSNs where various interesting challenges and research issues have been tackled. WSNs were previously only dedicated to catch data from an environment and to transmit them to a sink or base station. For this reason, many researches focus on new methods to transmit data efficiently in order to reduce the energy consumption [**?**], [**?**] or to guarantee messages arrival [**?**], [**?**].

II. Related works

In the literature, the most related work about a comparative study of routing protocols can be found in [**?**]. Authors crossed back and forth many routing protocols. They proposed for WSNs different categories for these routing protocols such as Location-based protocols, Data-centric Protocols, Hierarchical Protocols, Mobility-based Protocols, Multipath-based Protocols, Heterogeneity-based Protocols and QoS-based protocols. In [**?**] authors analyze the design issues of sensor networks and present a classification and comparison of theses routing protocols. They give a selection of specific routing protocol adapted for specific application in different areas. They show by their study it is not possible to design a routing algorithm which will have good performance under all scenarios and for all applications.

We can find in [**?**] a very good comparative study for proactive and reactive routing protocols, where authors evaluate four ad hoc routing protocols such as DSDV, TORA, DSR and AODV in NS-2. In literature, we can find many studies and improvements about these routing protocols. In [**?**] and [**?**], authors analyze performance about AODV and DSR routing protocols. In [**?**] authors compare AODV and DSDV with an Optimized-AODV routing protocol, which provides better results than AODV and DSDV. In [**?**] authors present AOMDV, and show that AOMDV always offers a superior overall routing performance than AODV in a variety of mobility and traffic conditions. In [**?**] the authors study and compare the performance of the following routing protocols AODV, PAODV (Preemptive AODV), CBRP, DSR and DSDV. They show that CBRP has a higher overhead than DSR because of its periodic hello message while AODV's end-to-end packet delay is the shortest when compared to DSR and CBRP, and PAODV has shown little improvements over AODV. In [**?**], the authors evaluate the performances of three routing protocols DSDV, FSR and OLSR DSDV, FSR et OLSR using the NS2 framework. The study varied the network density as well as network workload. Their main conclusion is that OLSR is much more evolutive but FSR is much appropriate for higher network workload.

In all these studies, the authors compare only performance about routing protocols or propose an improvement but they do not analyze about the impact of the MAC layer or the transmission range.

The following references are dedicated to MAC protocol analysis. In [**?**], the authors analyze the performance of IEEE 802.15.4 LR-WPAN in large-scale WSN applications. Their analysis consist in the study of CSMA-CA mechanism and MAC operation in a beacon-enabled cluster-tree structure. They analyze performance in terms of power consumption and goodput of coordinator. The results are verified with WIreless SEnsor NEtwork Simulator (WISENES).

S-MAC is a well known protocol [**?**] for the WSN-scientific community. The S-MAC protocol principle is based on a number of frame delays willing to communicate. Indeed, a frame has two equivalent periods: a wake-up period and a sleep period. Nodes synchronization will occur in a neighborhood node and where they exchange their calendars. In a wake-up period, two nodes in a wake-up status will be kept active during the communication duration. After communication, nodes go to the sleep mode their transceivers are off). T-MAC and B-MAC investigate adaptive Wake-up/Sleep periods. In these protocols, when a node detects that a medium is busy, goes to a sleep mode in order save more energy and reduce a collision risks with its neighbors. Other protocols [**?**], use a common Òcontention based control periodÓ where nodes communicate pairwise to coordinate their schedules. This common negotiation period wastes energy when traffic is light, as all nodes must be awake during this period. sensor.

In [**?**] authors deal with two categories of MAC techniques: contention based and schedule based. They give a unique performance analysis and comparison of benefits and limitations of each protocol. They show that for random topology contention based approach may be helpful and also schedule based approach may be more energy efficient if deployment is not random. In [**?**], authors present X-MAC a MAC protocol whose main objectives are: energy-efficiency, simple, low-overhead, distributed implementation, low latency for data, high throughput for data and applicability across all types of packeting and bit stream digital radios. They compare X-MAC and LPL. In [**?**] authors show that X-MAC provide a power-saving mechanism for routing nodes in Contiki simulator. With this method they show that X-MAC reduces the power consumption for ZigBee routing nodes with up to 90%.

In [**?**] [**?**] we have proposed a MAC protocol based on a technique able to schedule communications over all nodes in an ordered way. For this reason, we build an abstract ring between all nodes. This structure will contribute to assign a specific slot for each node in order to listen its previous neighbour, to compute aggregated data and to send modified data to its next neighbour. This method ensures to save high amount of energy since each node spends more time in the sleeping mode than usual methods

III. Parameters of the Study

In this section, we detail all protocols we use in order to produce our impact study.

A. IEEE 802.15.4

In the next sections, we show the IEEE 802.15.4 standard features of the physical and Medium Access Control (MAC) layers for Low-Rate Wireless Personal Area Networks (LR-WPAN) [**?**].

1) Physical Layer: The physical layer uses the Direct Sequence Spread Spectrum (DSSS) access mode in three frequency bands 2450 MHz (with 16 channels), 915 MHz (with 10 channels) and 868 MHz (with 1 channel).

Besides radio on/off, the physical layer gives some functionalities for channel selection, link quality estimation, energy detection measurement, and clear channel assessment to assist the channel selection.

2) MAC layer: The IEEE 802.15.4 MAC layer defines two types of nodes: **Full Function Devices** (FFDs) and **Reduced Function Devices** (RFDs). FFDs are equipped with a full set of MAC layer functions. They can be coordinators or end-devices in the network. In the coordinator mode, FFDs can send beacon, offering synchronization, communication and network join services. FFDs can communicate with other FFDs or RFDs. Besides, RFDs are equipped with a reduced set of MAC layer functions. They can only be end-devices for sensing. In a network, each RFD can communicate only with a single FFD.

The MAC layer has two modes for medium access:

1) **Nonbeacon mode:** The medium access is purely based on the CSMA/CA (Carrier Sense Multiple Access) /(Collision Avoidance) mechanism.
2) **Beacon mode:** The PAN coordinator operates with a Superframe. It starts the Superframe with beacon for node synchronization. The Superframe contains an active and an inactive portion where nodes may move to the sleeping status and then save energy. The active portion contains fixed size slots which represent two periods: a Contention Access Period (CAP) where nodes use CSMA/CA mechanism, and a Contention Free Period for large packets or time-critical data deliveries assigned by the PAN coordinator. Synchronization and sending (non GTS) operations are executed in the CAP period. Informations for pending delivery are in the beacon frame.

B. Routing Protocols

Routing protocols are required to ensure multi-hop communications. Indeed, if nodes are within the range of each other, a routing protocol is not necessary. Nodes can move or would communicate with a node out of their range. Intermediate nodes are needed to organize the network which takes care of data transmission. Routing protocols must choose some criteria to make routing decisions, for instance the number of hops, latency, transmission power, bandwidth, etc. Routing protocols are divided into two basic classes:

- Proactive routing protocols and
- Reactive routing protocols

For each class of routing protocols above, we present an example:

1) DSDV Routing Protocol: Destination-Sequenced Distance Vector routing is one of the well known proactive routing protocols for ad hoc mobile networks. It is based on the Bellman-Ford algorithm. Each node maintains a routing table that contains: all possible Destinations, Hop Count for each Destination and Sequence number to distinguish between old and new route that solve routing loop problem. When nodes update their routing table, they update their sequence number for each recent route to guarantee the freshness of a route. DSDV solves two issues: routing loop issue and counting to infinity. However, a node must wait for a destination update to set its entry in its routing table.

2) AODV Routing Protocol: Ad-hoc On-Demand Distance Vector is based on the Bellmann-Ford distant vector algorithm for ad-hoc networks. When a node needs to send a packet to a destination, AODV uses a mechanism of *Route Discovery* to built a route. It uses also a *Route Maintenance* for errors. Route Discovery consists of RREQ (Request) and RREP (Reply) when a node would like to send a packet. Route Maintenance consists of RERR messages, HELLO messages and precursor lists. Sequence numbers provide fresh routes and avoid routing loops.

All nodes monitor their own neighbors. When a node in an active route gets lost, a route error message (RERR) is sent to notify the link lost. Nodes use a HELLO message to inform only neighbors that the link is still alive. When a node receives a HELLO message it refreshes its lifetime from the neighbor information in the routing table. More details about the algorithm and its implementation could be found in [**?**].

3) AOMDV Routing Protocol: The Ad Hoc On-demand Multipath Distance Vector Routing is a improvement of AODV. Contrary to AODV, AOMDV discovers multiple paths between the source and the destination during the route discovery operation. It is more efficient for highly dynamic ad hoc networks since errors occur frequently. The AOMDV protocol has two main principles:

- a route update rule to establish and maintain multiple loop-free paths at each node.
- a distributed protocol to find link-disjoint paths.

Multipath routing protocols, such as AOMDV, try to reduce the high latency of route discovery, which can decrease performances.

4) DSR Routing Protocol: Dynamic Source Routing (DSR) is a reactive protocol such as AODV and AOMDV. It is similar to the AODV protocol which creates a route on-demand when a node needs to send to a destination. However,contrary to AODV, DSR uses source routing. DSR accumulates the address of each node between the source and the destination. This path information is coached by nodes processing the route discovery packets. With this routing protocol, each node contains the address of each intermediate nodes. It results a high overhead for high dynamic networks.

The main disadvantage of this protocol is that a broken link is not locally repaired by the route maintenance mechanism. The connection setup delay is higher than in table-driven protocols. In static and low-mobility, DSR behaves with high efficiency. But due to source-routing, routing overhead increases when mobility and path length increase too, so performance decreases quicky.

C. Default protocol values

Many criteria could be analyzed in various layers in order observe network performances.

- Transport layer: the Retransmission TimeOut (RTO) and the Congestion Window Limit (CWL),
- Network layer: Routing metrics,
- MAC layer: Backoff parameter and maximum retries number.

The usual default values are as follows:

- The (RTO) has an adaptive value as defined in RFC-6298 and the CWL value is usually 8.
- The most used routing metrics is the Minimum Hop Counter defined in for each routing protocol.
- The maximum retries number is 3 for the 802.15.4 protocol.The backoff is calculated by an exponential mechanism: the initial value is from 0 to 7. It could double the backoff range as 0 to 15 or 0 to 31.

As we see, default values have been proposed in the past for wired networks and have been used for any type of network. But for wireless networks, the adaptation have to be considered seriously in order to be sure to have better performances of the network in terms of goodput.

IV. Experimentations

A. Working environment

We use the well-know NS-2 simulator [**?**] to develop our experimentations.We use a Peer-to-Peer topology with one PAN coordinator. All nodes are FFDs using $240MHz$ band frequency and $250kps$ bandwidth. We use AODV, AOMDV, DSDV and DSR routing protocols in in a beacon-enabled mode.

Nodes can reach their neighbors located in their transmission range. Transmit power is set to minimum to increase number of hops along routes between two endpoints. We followed two steps for simulation. One for the synchronization between nodes, and another one for the application execution. the total duration is different for each simulation because nodes synchronize within different durations in a beacon-enabled mode. In all simulations, application time is 250 $seconds$. We use a $interval\_sync$ to start nodes at different intervals to reduce the synchronization time.

We adopted two scenarios for the transfer of the same data file from one node to another.

- A static scenario: the packets will follow predetermined routes of different lengths
- A dynamic scenario: the packets will follow routes which will be proposed by routing protocols. That means the routes will change during the file transfer.

For the transport layer, we handle the RTO algorithms and we compared three different options:

- A static value: a Random value is chosen in a static interval
- A semi dynamic value: Calculate Round Trip Time (RTT) once during session establishment and use a multiple of it as RTO (RTO = 4*RTT).
- A full dynamic value: Calculate RTO based on SRTT, RTTVAR as proposed in RFC6298.

B. Result analysis

We have conducted various experimentations using the same map with the same number nodes fixed at the same location for all simulations. We only look after the bandwidth use. In Figure. 1, we show the value of the goodput percentage in static routing with the AODV protocol. The increase of the number of hops does not have any influence on the goodput but the CWL value is better for the value 1. This result is not expected since the increase of CWL usually increases the goodput. In this case, the best performances are for CWL equal to one. In such case the retransmission ratio is very low then the bandwidth use is quite high.

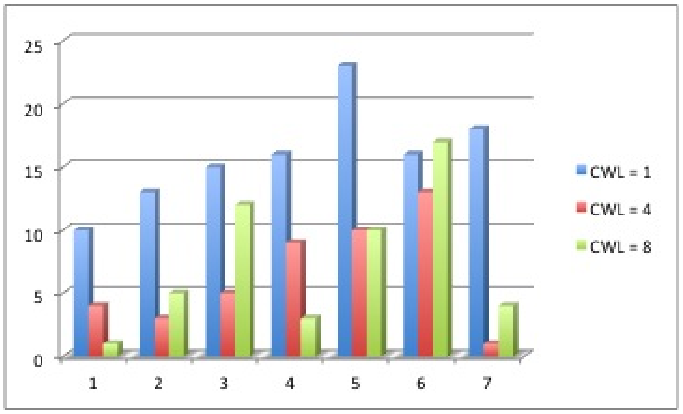

Figure 1: Goodput according to the CWL size

In Figure. 2, the ratio transfer is shown for 3 values of CWL (1, 4 and 8) as experimented in Figure.1. When the number of MAC retry number increases, the transfer ratio increases. As we observe, the best combination is CWL equal to one and MAC retry number equal one. It is not as in the wired networks where the increase of CWL size induces the increase of the transfer ratio.

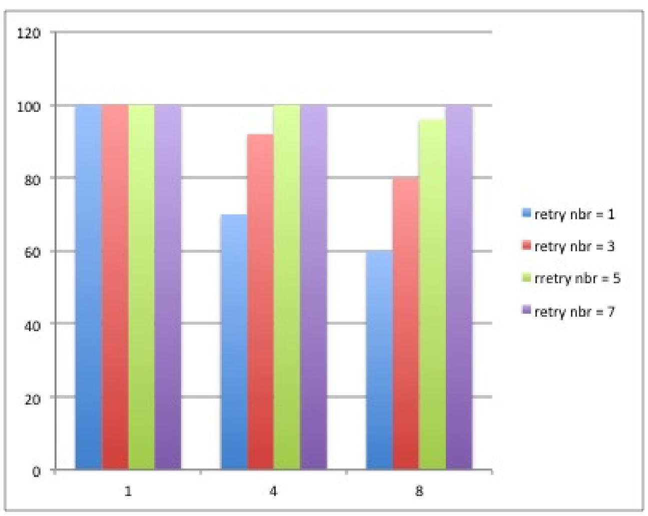

Figure 2: MAC retries

The results shown in the figures below, deals only with the AODV protocol. For the 3 other protocols (DSR, DSDV and AOMDV) the results are less interesting.

V. Conclusion and future work

In this study, we analyzed how to improve TCP performances over wireless networks. Our aim is to provide an automatic tool able to choose the best parameters values of each protocol under the transport layer (in particular with TCP) in order to reach the best use of the network bandwidth. We have shown by means a set of experimentations, using the NS-2 toolbox, that default values are some how suitable but should be adaptive in each specific situation.

The actual study is still in progress to a da

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