Demo Abstract: Z-Monitor: A Monitoring Software for IEEE 802.15.4 Wireless Sensor Networks

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***Abstract*—Monitoring of Wireless Sensor Networks (WSNs) is a fundamental task to track the network behavior and measure its performance in real-world deployments. Commercially-available products for monitoring and testing IEEE 802.15.4-compliant Low Power Wireless Personal Area Networks (LoWPANs) are mainly too expensive, and typically require special sniffing hardware. In this Demo paper, we present our tool Z-Monitor, a monitoring and a protocol analyzer solution to control and debug IEEE 802.15.4-compliant LoWPANs. Z-Monitor represents a free and extensible solution for monitoring Zigbee, 6LowPAN and RPL protocols, does not require special sniffing hardware, and provides comparable services to proprietary and commercial products.**

I. Introduction

LoWPANs are typically composed of devices that conform to the IEEE 802.15.4-2006 standard. While IEEE standard 802.15.4 specifies the Physical and Medium Access Control (MAC) layers and underlying services for LoWPANs, upper layers like Network and Application layers are defined by other standards like ZigBee [1], 6LowPAN [2] and RPL [3]. Despite the fact that ZigBee and 6LoWPAN/RPL are arguably the most important WSN technologies today, very little is available on network monitoring and debugging of these networks. In this Demo, we present Z-Monitor [4], a modular application for monitoring and controlling IEEE 802.15.4-compliant LoWPANs. Z-Monitor provides a convenient solution for researchers and students for developing, debugging and deploying wireless sensor network applications based on IEEE 802.15.4 standard protocol and underlying network protocols (i.e. 6LoWPAN, ZigBee, RPL). Z-Monitor is compatible with the open-source official TinyOS implementation of the IEEE 802.15.4 recently released by the TinyOS 15.4 Working Group [5]. It also provides support for both ZigBee and 6LoWPAN [2], the two mostly used protocols deployed over LoWPANs.

II. Z-Monitor in Brief

Z-Monitor provides an open source, extensible, modular and user-friendly solution for LoWPAN monitoring. Z-Monitor allows for passive monitoring of IEEE 802.15.4-based networks and for analyzing the network behavior through statistical data analysis. Z-Monitor relies on a particular sensor node acting as a passive sniffer that captures network traffic and redirects it to a user-friendly Graphical User Interface (GUI). The fundamental advantage of Z-Monitor as compared to commercially available products such as CC2420 Sniffer [6], Daintree Network Analyzer [7] and Zena [8] is that it is independent of any special hardware and simply relies on a simple mote to capture traffic.

A component-based approach has been used to design Z-Monitor. The block diagram of the main components is shown in Fig. 1.

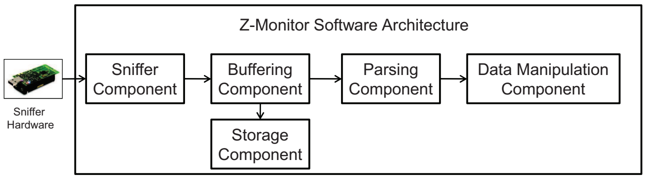
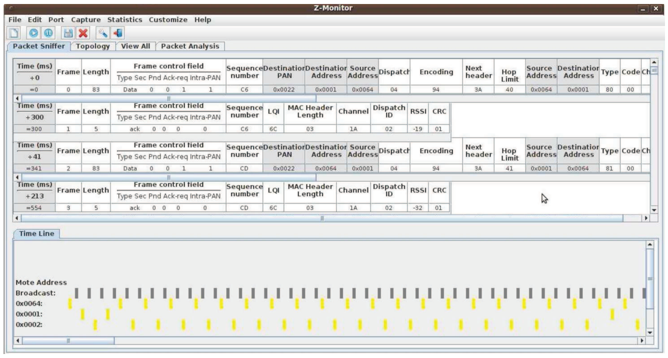


Fig. 1: The Block Diagram of Z-Monitor

On the hardware side, the *sniffer hardware* is simply an IEEE 802.15.4-compliant sensor mote, which passively captures the network traffic. Each received packet is redirected to the serial interface through which the sniffer is attached to forward that packet to the software sniffing threads. The sniffer hardware that we have used is a TelosB mote [9] that implements `tknsniffer` application available under TinyOS. The `tknsniffer` application switches the radio chip into promiscuous mode and subsequently sniffs all packets that come along. Z-Monitor collects packets arriving from the USB port, stores them in a buffer, performs parsing and packet decoding and finally displays parsed frames and outputs network statistics as depicted in Fig. 2.



Time (ms)	Frame	Length	Frame control field					Sequence number	Destinatior PAN	Destinatior Address	Source Address	Dispatch	Encoding	Next header	Hop Limit	Source Address	Destinatior Address	Type	Code	Ch
+0			Type	Sec	Pnd	Ack-req	Intra-PAN													
=0	0	83	Data	0	0	1	1	C6	0x0022	0x0001	0x0064	04	94	3A	40	0x0064	0x0001	80	00	

Time (ms)	Frame	Length	Frame control field					Sequence number	LQI	MAC Header Length	Channel	Dispatch ID	RSSI	CRC
+300			Type	Sec	Pnd	Ack-req	Intra-PAN							
=300	1	5	ack	0	0	0	0	C6	6C	03	1A	02	-19	01

Time (ms)	Frame	Length	Frame control field					Sequence number	Destinatior PAN	Destinatior Address	Source Address	Dispatch	Encoding	Next header	Hop Limit	Source Address	Destinatior Address	Type	Code	Ch
+41			Type	Sec	Pnd	Ack-req	Intra-PAN													
=341	2	83	Data	0	0	1	1	CD	0x0022	0x0064	0x0001	04	94	3A	41	0x0001	0x0064	81	00	

Time (ms)	Frame	Length	Frame control field					Sequence number	LQI	MAC Header Length	Channel	Dispatch ID	RSSI	CRC
+213			Type	Sec	Pnd	Ack-req	Intra-PAN							
=554	3	5	ack	0	0	0	0	CD	6C	03	1A	02	-32	01

Fig. 2: Z-Monitor Frame Decoding Interface

III. Experimental Study

A. Network Test-Bed and Objectives

We present an experimental study that shows how to perform monitoring and performance evaluation of ZigBee, 6LoWPAN and RPL protocols using Z-Monitor. The objectives of the experimental study are manifold:

- To demonstrate the capabilities of Z-Monitor for network monitoring.
- To validate Z-Monitor tool's support for various IEEE 802.15.4-based networks.
- To show how Z-Monitor is useful in evaluating the performance of IEEE 802.15.4-based WSNs.
- To present the collection of network statistics using Z-Monitor.

The network topology scenario used in the following experiments is composed of 12 TelosB motes in an indoor environment as presented in Fig. 3. In detail, the demonstration consists of the following components:

1) One sniffer mote (running `tknsniffer` TinyOS application);
2) One Base Station (playing the role of the PAN coordinator, e.g., running `IPBaseStation` TinyOS application for BLIP [10] or `uip6-bridge` [11] for Contiki that does the bridging to the nodes running uIPv6)[1];
3) 10 identical nodes distributed around the Base Station;
4) A Notebook with installed TinyOS 2.x operating system.

Currently, Z-Monitor can be used to monitor and analyze Open-ZB [12], BLIP, uIPv6 and ContikiRPL [13] implementations. In fact, this demonstration shows how Z-Monitor performs the parsing and decoding of all IEEE 802.5.4-2006 standard frames, the evaluation and comparison of two well-known 6LoWPAN implementations, i.e., uIPv6 on Contiki and BLIP on TinyOS, and evaluate the performance of the recently drafted RPL routing protocol under Contiki operating system.

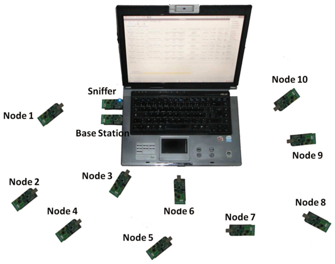


Fig. 3: Experimental Testbed

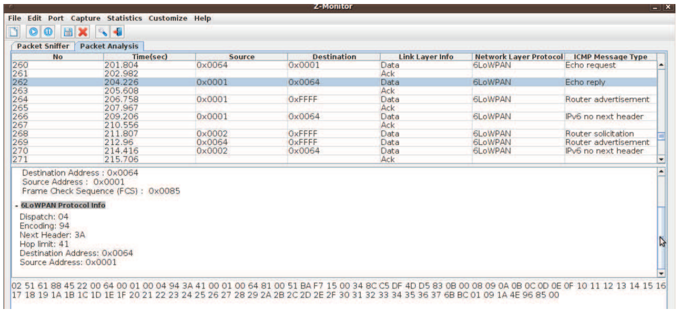
B. Demonstration Highlight

In our demo, TelosB motes will be deployed within a single broadcast domain, i.e. a single-hop network. Z-Monitor for multi-hop networks is still underway; therefore we will present results from a single-hop network testbed. The transmission power of nodes was set to -25 dBm and the frequency channel was set 26. We consider the available open-source implementations of ZigBee and 6LoWPAN protocols namely, the TinyOS IEEE 802.15.4/ZigBee implementation, the TinyOS 6LoWPAN implementation (BLIP), the Contiki 6LoWPAN implementation (uIPv6) without and with RPL support (ContikiRPL).

For the demo, we have chosen two scenarios showing the capabilites of the Z-Monitor tool. They are described below:

- Scenario 1. In this scenario we want to demonstrate the parsing and decoding functions of the tool when a Zigbee Cluster Tree is formed using the beacon enabled version of the IEEE 802.15.4-2006 standard. We use one PAN coordinator and 10 end devices. The end devices associate to the coordinator and send a single packet to the coordinator after receiving every beacon. The sniffer mote attached to the laptop will sniff the frames and send packets received via the serial port to the PC to be analyzed by Z-Monitor. The performance of Z-Monitor are compared against a CC2531 Evaluation Module Kit [14], composed by one CC2531DK Dongle USB radio sniffer and the TI Packet Sniffer tool. The parameters to analyze are the packet reception rate and the decoding function of the tool.
- Scenario 2. In this scenario, we want to demonstrate the ability of Z-Monitor to receive 6LoWPAN packets. To this end, we install the `UDPEcho` application from the TinyOS implementation in the ten nodes. This application provides a UDP echo service. After installing, we can generate traffic by simply sending *ping6* commands to each node from the the node attached to the PC with the base station application is installed. We can monitor the traffic in Z-Monitor through the sniffing mote connected to the laptop, and compare its performance (packet reception ratio and the correct decryption of packets) against the WireShark [15] tool. Fig. 4 shows a screenshot of the planned demo that demonstrates the capture and analysis of BLIP packets with Z-Monitor.

[1] This second option will not be shown during the demo, but it is feasible if the final user wants to try



No	Time(sec)	Source	Destination	Link Layer Info	Network Layer Protocol	ICMP Message Type
260	201.804	0x0064	0x0001	Data	6LoWPAN	Echo request
261	202.982			Ack		
262	204.226	0x0001	0x0064	Data	6LoWPAN	Echo reply
263	205.608			Ack		
264	206.758	0x0001	0xFFFF	Data	6LoWPAN	Router advertisement
265	207.967			Ack		
266	209.206	0x0001	0x0064	Data	6LoWPAN	IPv6 no next header
267	210.556			Ack		
268	211.807	0x0002	0xFFFF	Data	6LoWPAN	Router solicitation
269	212.96	0x0064	0xFFFF	Data	6LoWPAN	Router advertisement
270	214.416	0x0002	0x0064	Data	6LoWPAN	IPv6 no next header
271	215.706			Ack		

```
Destination Address : 0x0064
Source Address :  0x0001
Frame Check Sequence (FCS) :  0x0085

- 6LoWPAN Protocol Info
Dispatch: 04
Encoding: 94
Next Header: 3A
Hop limit: 41
Destination Address: 0x0064
Source Address: 0x0001

02 51 61 88 45 22 00 64 00 01 00 04 94 3A 41 00 01 00 64 81 00 51 BA F7 15 00 34 8C C5 DF 4D D5 83 0B 00 08 09 0A 0B 0C 0D 0E 0F 10 11 12 13 14 15 16
17 18 19 1A 1B 1C 1D 1E 1F 20 21 22 23 24 25 26 27 28 29 2A 2B 2C 2D 2E 2F 30 31 32 33 34 35 36 37 6B BC 01 09 1A 4E 96 85 00
```

Fig. 4: BLIP Protocol Analysis using Z-Monitor

With this demo, we also show how Z-Monitor can be used to measure the performance of the different protocols. With Z-Monitor, users can measure the *network convergence time* metric of each router node, which is the duration a node spends to join the 6LoWPAN network for all implementations under study (i.e.Open-ZB, BLIP, uIPv6 and ContikiRPL), and this is done through observing the arrival time of the packets. Fig. 5 shows an example of measuring the convergence time of a 6LoWPAN network with Z-Monitor in which we compare the performance of uIPv6 and BLIP implementations. To do so, we measured the time when a node receives a router advertisement message from the Base Station for both the implementations.

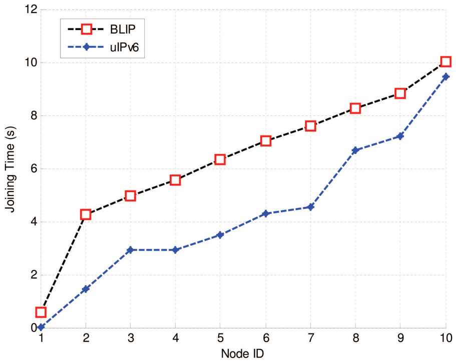


Fig. 5: Convergence Time of 6LoWPAN with BLIP and uIPv6

We show also through this demo that Z-Monitor can be used also to measure the throughput and the delay of packet transmission.

IV. Conclusions and Future Works

The proposed demonstration explains the capabilities of our tool Z-Monitor to monitor, analyze protocols and evaluate the performance of COTS WPANs technologies namely IEEE 802.15.4, ZigBee, 6LoWPANs, and RPL protocols. Z-Monitor is compatible with all open-source implementations of these protocols provided by TinyOS and Contiki operating systems.

We are currently working towards extending Z-Monitor to support more advanced features including (1) support of multi-hop topologies through the use of multiple sniffers so that it will be easier and practical to analyze the behavior of large scale networks, (2) extending parsing component to support new COTS protocols implementations such as TinyRPL, which has recently been released, (3) integrating advanced filtering and statistical analysis features.

V. Acknowledgments

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