Performance Evaluation of 6LoWPAN Based Networks for Ubiquitous Health Monitoring System

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Abstract— *Machine-to-Machine (M2M) networks have become very useful in a wide range of applications such as ubiquitous healthcare (u-healthcare) monitoring, air quality monitoring, insect monitoring, etc. Such applications require providing Internet connectivity to wireless sensor networks for the purpose of data collection and gathering. IPv6 over low power wireless personal area network (6LoWPAN) protocol specifications support the Internet-of-Things (IoTs), through an adaptation layer that provides efficient header compression. The 6LoWPAN middleware constitutes a crucial enabling technology for M2M networking. An optimum deployment of a 6LoWPAN-based system requires an accurate evaluation of the 6LoWPAN network's performance. Among various metrics, throughput and Packet Error Rate (PER) are of paramount importance, especially for time-critical and delay sensitive applications. In U-Health System where real-time ECG monitoring requires high throughput with reduced PER, an intolerable level of latency could result into lethal effects on patients. Thus, the performance of Wireless Sensor Network (WSN) used in U-Health should conform strictly to the timeliness requirement of health monitoring applications. In this study, we consider a system architecture where a 6LoWPAN node acts as a proximity body sensor to form a Wireless Body Area Network (WBAN) for a given patient. The objective of the study aims at assessing the scalability range of 6LoWPAN based WBANs and at estimating whether the performance bounds of such networks can serve efficiently u-healthcare applications. We evaluate the network performance by simulating different scenarios using Cooja (a Contiki-Network Simulator). Scenarios of a Constant bit rate (CBR) traffic and a Variable-Bit-Rate traffic are simulated, emulating real life biomedical data (e.g., ECG, temperature, etc.). The CBR-based scenario is conceived to determine the verge of the 6LoWPAN network in acute cases of U-Health system. Through simulation we demonstrate the viability of the performance bounds of the 6LoWPAN-based WBAN for u-healthcare applications.*

Keywords: 6LoWPAN, WBAN, Contiki OS, Performance evaluation, Scalability

1. Introduction

Wireless Sensor Networks (WSNs) have been increasingly deployed in the past few years and have earned significant importance in various application areas such as medical, environmental, agricultural, telecommunications, etc. Several applications require connectivity between the wireless sensor network and the Internet [1].

Sensor networks have been a fertile research area, during the recent years [2], for health monitoring systems. Examples of application include remote patient monitoring, wearable/portable health monitoring systems, patient data logging for analysis and diagnosis and so forth [3]. Sensor networks in general and wireless sensor networks (WSNs) in particular are constrained with respect to networking capabilities. Recently, the advent of the 6LoWPAN as an enabling technology allowed IPv6 packets to be carried on WSNs up to the level of the final sensing node, thus materializing the Internet of Things paradigm [4]. The 6LoWPAN feature is specified as an adaptation layer that does header compression allowing large IPv6 headers to shrink into smaller headers with sizes between 40 and 211 bytes [5].

Numerous U-Healthcare systems have been presented in the literature [6], [7], [8]. In these systems, researchers have developed either their own protocols on top of IEEE 802.15.4 MAC or have used Zigbee or other proprietary protocols. However, with all these protocols, the interoperability of their smart devices remains a challenge. In this context the 6LoWPAN specifications (an open standard proposed by IETF), have been branded as the solution for the efficient use of IPv6 packets over low-power, low-rate wireless networks, thus allowing network visibility for all involved embedded devices [9]. In addition to efficient header compression, key features of 6LoWPANinclude automatic network configuration using neighborhood discovery, unicast, multicast and broadcast support, fragmentation support, IP routing (using the Routing Protocol for Lossy channels (RPL)) and support for link layer mesh topology formation (e.g., IEEE 802.15.4) [10], [11].

In this paper, we carry out a scalability analysis based performance evaluation of a 6LoWPAN network intended for use with u-health monitoring applications. We are using common performance metrics such as data throughput, Packet Error Rate (PER), delay and deliverability ratio in order to characterize the 6LOWPAN network's behavior for a U-Healthcare monitoring system.

The remainder of this paper is as follows. Section 2 describes the simulation setup. Simulation results are presented in section 3, and their analysis are given in Section 4. Finally, section 5 presents concluding remarks.

2. Simulation setup

We present a simulation-based evaluation of a 6LoWPAN network using Cooja, a Contiki Network simulator. We used a built-in Zolertia mote model provided by the Contiki OS [12], an operating system dedicated to execute IoTs applications. Contiki OS provides a complete set of tools that are required to create 6LoWPAN-based networks further, in Contiki OS program can directly simulated or emulated on a device. We simulated 6LOWPAN using the Cooja simulator and the emulated built-in Zolertia motes. Cooja allows large and small networks of Contiki motes to be simulated. Motes can be emulated up to the hardware level.

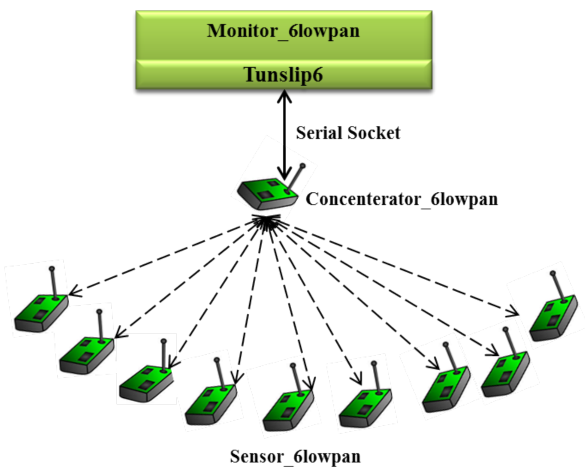

Fig. 1: Complete test bench with Cooja scenario for performance evaluation of 6LOWPAN network

To simulate the 6LoWPAN Network two scenarios are investigated; Constant Bit Rate Scenario (CBR) and Variable Bit Rate Scenario (VBR). In fact, in U-Healthcare system each sensor node has different rate of transmission rate. To emulate U-Healthcare system VBR scenario is simulated, however in some acute cases or in emergency cases transmission rate of the sensor can be changed depending upon the condition of the patient. In order to emulate that case we simulated CBR traffic. In CBR every sensor node is generating equal traffic at the same time and making equal contribution in throughput. If a certain level of the throughput can be achieved with reasonable PER in CBR then acute cases of U-Healthcare system can be managed.

The simulated network is sketched in figure 1. It is essentially made up of several sensor nodes (referred to as *sensor_6lowpan*), one edge router (referred to as *concenterator_6lowpan*), a Serial Line Internet application "tunslip6", and multithreaded application (referred to as *monitor_6lowpan*).

As sensors send packets to the concenterator_6lowpan, the monitor_6LoWPAN computes the average transmission delay between two contiguous received packets. Tunslip6 emulates a network interface on a PC. Tunslip6 acts as a bridge between the concentrator_6LoWPAN and monitor_6LoWPAN. Monitor_6lowpan performs computations according to the test discussed later in this paper. To obtain the results for analysis, number of simulations was performed. The simulation parameters are shown in table 1.

Table 1: General simulation parameters

Parameter name	Value
MAC layer	CSMA/CA
Radio duty cycling algorithm	Contiki MAC
Radio model	Undirected graph model
MAC layer queue size	8 packets
Bit rate	250 kbps
Node transmission range	50 Meter
Node carrier sensing range	100 meter
Simulated node type	Zolertia

3. Simulation results

During simulation, we measured the following quality of service (QoS) parameters:

- throughput against Packet Generation Interval (PGI) and offered traffic, and
- PER against the Packet Generation Interval

Throughput and PER were measured in both CBR and VBR. In each case, several network densities were considering, varying from 1 to 6.

CBR is used to determine the upper bound of throughput for the U-Healthcare monitoring system.

3.1 Constant bit rate scenario

Throughput vs Packet Generation Interval

The purpose of this simulation is to determine the effect of Packet Generation Interval on 6LoWPAN throughput, which affects the frequency of packet transmission of biomedical sensor. This simulation was conducted to measure the throughput as a function of the PGI for different network densities (Sensor_6Lowpan varying from 1 to 6) and with packet retransmission time 100ms.

We consider the topology shown in figure 1, where sensor_6lowpan transmitting directly to a concentrator_6lowpan. Various measurements were carried out in correspondence to different values of PGI. The repetition in simulation was made by incrementing the network density from 1 to 6. We analyzed the 6LoWPAN throughput as function of PGI up to six sensor nodes to accommodate six biomedical sensors (ECG, Accelerometer, Temperature, Heart Rate, Glucose and Blood Pressure) used in our U-Healthcare monitoring system.

figure 2 shows the performance of the throughput as a function of PGI. In figure 2, as we proceed from left to right, throughput increases linearly till particular value, for every incrementing sensor node, thereafter it starts decreasing exponentially due to decrease in rate of offered traffic, hence increasing PGI. We observed that offered traffic cannot reach the maximum data rate of the physical layer due to hardware and channel limitation.

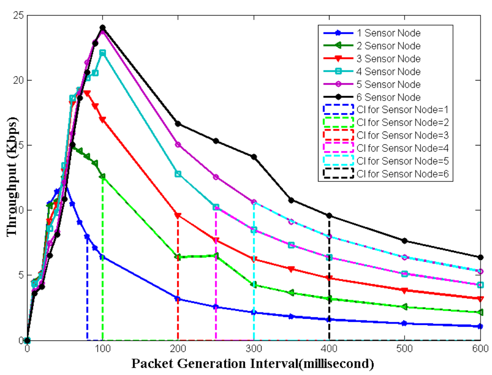

Fig. 2: Throughput measurement results for 6LOWPAN network as a function of Packet Generation Time

Packet Error Rate (PER) /Packet Delivery Ratio (PDR) vs Packet Generation Interval (PGI)

The communication system can be characterized in terms of connectivity or homogenously by the PER/PDR, as the connectivity of the link depends upon the routing protocol and on the packet retransmission mechanism under CSMA/CA [9]. Contiki uses RPL for routing and CSMA-CA for retransmission mechanism.

Figure 3 shows PER with respect to PGI, at different network densities of the 6LoWPAN network. Initially when the PGI is low PER is very high even in the case of one sensor node. As PGI increases PER starts decreasing up to an instant at which PER approaches to zero, from that instant onwards interval is called Confidence Interval (CI).

PDR/PER was measured using the simulation setup shown in figure 1. In figure 3, simulation results for PER/PDR shows that for lower value of PGI, the packet loss is high, even for one Sensor_6lowpan, packet lost is present up to 80ms PGI. Table II shows the confidence intervals of PGI for each network density, with 100% PDR. These confidence intervals are estimated from the throughput and from PER shown in figure 2 and figure 3 respectively. Confidence interval indicates the CBR's maximum rate of the packet transmission, at which PER becomes zero. Performance parameter of 6LoWPAN i.e., for one Sensor_6lowpan PER ≈ 0 for more than and equal to 80ms PGI.

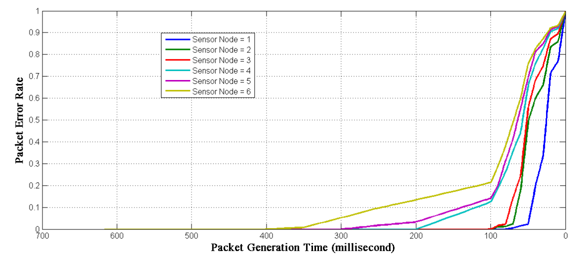

Fig. 3: Packet Error Rate

Table 2: CBR upper limit PER vs Confidence Interval (CI)

Network density	PER/PDR	CI
1	≈ 0 / ≈ 1	>=80ms , @80ms ~8Kbps
2	≈ 0 / ≈ 1	>=100ms, @100ms ~12.56Kbps
3	≈ 0 / ≈ 1	>=200ms, @200ms~9.6Kbps
4	≈ 0 / ≈ 1	>=300ms, @300ms~8.5Kbps
5	≈ 0 / ≈ 1	>=400ms, @400ms~8Kbps
6	≈ 0 / ≈ 1	>=600ms, @600ms~6.5Kbps

Throughput VS Offered Traffic

Among the commonly used sensors in U-Healthcare systems, the highest bandwidth requirement comes from ECG sensor. Figure 2 and table 2 shows that the maximum throughput with high PDR is around 100ms PGI. In acute cases of the U-Healthcare, if every sensor node transmits around 100ms PGI then there will be less chances of collision and will have high throughput, To attain maximum throughput of the system, we simulate the effect of increasing nodes on throughput at Packet generation Interval (PGI) = 100ms, Packet Retransmission Time = 100ms and Packet Length = 80bytes. The intention of this simulation is to measure the maximum throughput that can be offered by the 6LOWPAN. We measured the throughput by increasing the number of nodes, but our simulation shows that a practical network performance is still far from theoretical performance level as shown in figure 4.

In fact, only a throughput of 31 Kbps can be achieved in the presence of the maximum offered traffic load. We also noticed the throughput reached at its peak value for around 23 nodes. Thereafter, the throughput starts deteriorating as

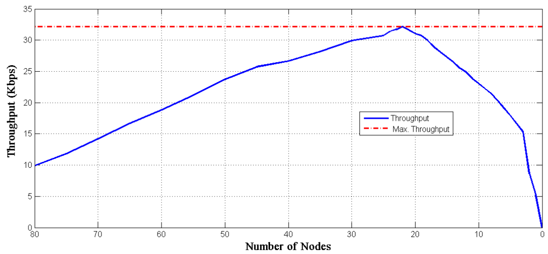

Fig. 4: 6LoWPAN Throughput as a function of Nodes

the number of nodes increases. This is due to high queuing and packet drops that starts occurring at high loads where the system has reached instability.

3.2 Variable bit rate scenario

CBR with low PGI is the worst case, where all nodes transmit with same transmission rate; which increase the collision probability. Whereas as described in table 3, VBR has less collision with respect to CBR because most of the sensors are in sleep mode except ECG node. To analyze the 6LOWPAN feasibility for U-Healthcare monitoring system, we emulate biomedical sensor in the Cooja with following parameters (i) rate of transmission frequency (ii) size of the data, the actual VBR model is described in table 3.

Table 3: Biomedical Sensor Data Statistics

Biomedical sensor type	Data to transmit	Transmission frequency (PGI)
ECG	Max ECG Frequency = 200Hz 1 second data with sampling frequency of 600Hz	15 packets PGI = 80ms
Temperature	2 bytes	1 packet PGI = 120s
Accelerometer	6 bytes	1 packet PGI = 120s
Respiration rate	1 bytes	1 packet PGI = 60s.
Glucose	4 bytes	1 packet PGI = 2s

VBR is considered a case where different proximity 6LoWPAN body sensors are connected to the patient and sending data to the system. As in VBR every sensor has particular PGI and sending at its own particular rate, the probability of collision of the packets is very low and it requires low throughput. The maximum throughput required by the system with these biomedical sensors (ECG, temperature, Accelerometer, Respiration rate) is: ~8Kbps -10Kbps (600Sample/second, each sample of 2 bytes with overhead of processing time of 200ms). In U-Healthcare system only sensor which is frequently using the channel is ECG sensor and using the maximum payload and other biomedical sensor can be integrated to one sensor node to efficiently use the payload and packet collision can be avoided. The WBAN can be emulated by only two sensor nodes (One sensor node is required for ECG sensor and the other sensor can be used to emulate the aggregated traffic of all the other biomedical sensors).

Table 4: Statistical Results: CBR and VBR

Network setup	Traffic description	Results
2 sensors	VBR PGI_{node1} = 80ms ; PGI_{node2} = 60second	Calculated Throughput = 8.64Kbps Measured Throughput ≈ 8.54Kbps PER = 0, PDR = 100%
	CBR Constant PGI = 80ms 80 bytes payload for both sensors	Throughput = 13.916Kbps PER = 0.1243, PDR = 87.57%
6 sensors	VBR PGI_{node1} = 80ms, $PGI_{node\ 2,3,4}$ = 120 s, $PGI_{node5,6}$ = 60 s	Calculated Throughput = 10.24Kbps Measured Throughput ~ 9.4Kbps PER = 0.023, PDR = 98.4%
	CBR PGI = 80ms, 80 bytes payload for all sensors	Throughput = 20.573Kbps PER = 0.3848, PDR = 61.52

4. Simulation results analysis

Table 4 shows the simulation results of the CBR and VBR of the 6LoWPAN body sensor network. For the simulation of two sensor nodes, if we compare throughput and PER of CBR and VBR, the throughput of the CBR is high as compare to VBR, which has zero PER. The difference in throughput is due to difference in offered traffic by these two systems. As we increase the number of sensor nodes up to six throughput of both system is increased but with some values of PER. The reason for such difference in PER is, in CBR each sensor node has same PGI and probability of packet collision is very high whereas in VBR each sensor has its own particular PGI and chances of collision is very low but it comes with a low value of throughput. The throughput achieved by VBR is reasonable for the U-Healthcare system with achievable packet delivery ratio is 98.4%.

5. Conclusions

In this paper we conducted a scalability based performance evaluation of the 6LoWPAN. In U-Healthcare system 6LoWPAN node acts as a proximity body sensor and these sensors form WBANs. In order to estimate throughput and PER of the WBAN we consider two traffic scenarios CBR and VBR. CBR scenario is used to simulate the acute cases of the U-Healthcare system and it exploits to estimate the max throughput limits of the 6LoWPAN network for VBR as shown in Table II; which is actually emulated as WBAN for U-Healthcare monitoring system. We found that 6LoWPAN network limits the node's transmission capability; primarily it limits the throughput and requires more packet generation interval for less PER. We record the Confidence Interval of the network for different network densities and it is different for every density. CI defines the node's transmission capability with zero PER, which helps us to design Wireless Body Area Network for U-Healthcare monitoring system. Simulated result indicates that the 6LoWPAN based system has reasonable throughput and PER for U-Healthcare system requirement for WBAN and has a big potential for U-Healthcare monitoring system.

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