Protocol Wireless Medical Sensor Networks in IoT for the Efficiency of Healthcare

El Miloud Ar-Reyouchi, Kamal Ghoumid, Doha Ar-Reyouchi, Salma Rattal, Reda Yahiaoui, Omar Elmazria

An Accelerated End-to-End Probing Protocol for Narrowband IoT Medical Devices

El Miloud Ar-Reyouchi, *Member, IEEE* Kamal Ghoumid, Doha Ar-Reyouchi, Salma Rattal, Réda Yahiaoui and Omar Elmazria, *Senior Member, IEEE,*

Abstract—In this study, a narrowband (NB) internet of things (IoT) medical device (MD) wireless communication system was established, in which a multi-hop source to the MD network shared the downlink and uplink resources to probe and control the MDs of hospital patients. A multicast data packet was distributed over the multi-hop MD networks, and a random linear network coding approach was applied in the source instead of the intermediate nodes. We evaluated the MD probe cycle between a master station and remote terminal units, which were connected with several critical devices in a medical room. Furthermore, an accelerated end-to-end (E2E) probing protocol was established in the wireless mesh network to minimize the probing cycle of the health devices. In particular, a faster protocol was developed to address the probe and control subproblem. The proposed approach could assist in realizing the accelerated E2E probing for NB-IoT MDs, reducing the number of retransmissions, recovering lost packets, and providing a prompt overview of the medical network performance, based on several basic parameters. Furthermore, in a comparative study of the contemporary probing cycle techniques, the proposed protocol notably outperformed several widely used protocols, with the improvements typically exceeding 71% and 60%, respectively.

Index Terms—accelerated end-to-end probing protocol, narrowband internet of things,wireless medical devices, network coding, wireless mesh networks.

1 Introduction

IN the present global crisis, the telecommunications infrastructure and services are playing a key role in ensuring the internet based connectivity of medical devices (MDs). In the current information age, MDs are widely used in healthcare facilities such as hospitals and clinics. Different types of MDs (e.g., heart-lung machines, medical ventilators,

dialysis machines, and incubators) offer various functionalities and work seamlessly to ensure that patients are adequately treated. In recent times, the artificial respiration procedure has been widely required for critically ill COVID-19 patients. In this context, the malfunctioning or disrupted operation of MDs can potentially result in loss of life [1]. With the accelerating global use of wireless sensors for MDs [2,3], a patient's health can be monitored remotely in a permanent and continuous manner. Such a medical network can help improve the quality of healthcare services. In this regard, the key concept behind the internet of things (IoT) framework is to authorize physical objects to communicate and exchange data using wired or wireless communication technologies to provide a specific functionality [4,5], to create a cooperative connection of specific entities. IoT MDs [6] offer several advantages, in terms of reducing medical errors, enhancing patient safety, and realizing patient-centric care delivery. The application of the IoT MD technology in probing tasks can help ensure that the doctors are well connected to the medical equipment through remote monitoring and virtual visits, thereby allowing the proactive monitoring of the patient health. The narrowband (NB)-IoT [7,8] for MDs [9] is a contemporary network technique that can be applied in any location and is widely used in hospitals and clinics. This framework is especially beneficial in several specific and critical applications, such as protection and health control [10] and probing cycle improvement [11]. The NB-IoT MD network is particularly advantageous as it has a large area coverage and enables the communication of many MDs, to detect, verify, and probe the proper functioning of these devices. Several researchers indicated that [12], in a given situation, the NB-IoT network may operate cooperatively with the long term evolution system. This framework can be applied in classical applications [13] involving smart health care monitoring [14] and intelligent metering. The physical layer of the NB-IoT has an RF bandwidth that yields a necessary device bandwidth

- *El Miloud Ar-Reyouchi is with the departement of telecommunication and computer science, E.T.S., Madrid, Spain and with Abdelmalek Essaâdi University, Morocco*
  E-mail: e.arreyouchi@m.ieice.org
- *Kamal Ghoumid is with FEMTO-ST Institute, University of Franche-Comté and with Department of Electronics, Informatics and Telecommunications, Mohammed First University,ENSAO, Oujda, Morocco*
  E-mail: k.ghoumid@ump.ac.ma
- *Doha Ar-Reyouchi is with Department of plastic and reconstructive surgery, Mohammed First University, Morocco*
- *Salma Rattal is with Department of Telecommunications,Hassan II University, Casablanca, Morocco*
- *Réda Yahiaoui is with NanoMedicine Lab, Therapeutic, Imagery, Franche-Comte University. Besançon, France*
- *Omar Elmazria is with Université de Lorraine, CNRS, Institut Jean Lamour, F-54000. Nancy, France*
  E-mail:Omar.elmazria@univ-lorraine.fr
  .

Manuscript received XXXX XX, XXXX; revised XXXX XX, XXXX.

of 200 kHz, in combination with a downlink (master station to slave station) and uplink (slave station to master station) duplex-frequency-division approach. The 200-kHz channel is split into 12 and 36 narrow-bandwidth sub-channels in the downlink and uplink directions, respectively [2]. The time-division multiplexing approach is adopted for each downlink and uplink subchannel to map the logical channels of the medium access control layer protocol to the physical channels. For resource allocation, a multiple access frequency-division (FDMA) or single-carrier FDMA (SC-FDMA) [15] combination and multiple access time-division (TDMA) can be established, as described in [16]. In general, the phase-shift keying modulation scheme, including a standard subcarrier and multiple subcarriers, is applied in both the uplink and downlink domains. Moreover, both the QAM and FSK modulation schemes can also be applied [17] to exploit the advantages of using different modulation rates [kbps]. In particular, in such scenarios, the various constraints on the signal propagation parameters lead to varying modulation rates. In a multi-hop mesh network, the downlink and uplink message lengths influence the round trip time (RTT) [18] and end-to-end (E2E) testing process. Complex modulation schemes [19] can be used to improve the spectral efficiency in several applications with a limited frequency spectrum. Some researchers proposed a fast and efficient probing FEP protocol to improve the probing capacities of heterogeneous IoT networks composed of the IEEE 802.11 and IEEE 802.15.4 subnetworks [20], which can enhance the efficiency of the network scans. This approach was based on obtaining RTT measurements with a modified probe length. In general, the performance of a medical network operating on an E2E PP cycle is based on several basic communication parameters, such as the modulation style, RF configuration headers, operating principle, modulation rate, forward error correction, acknowledgment [21], subcarrier spacing (SCS), information or message size, data transmission protocols, multiple storages, forward access points, total number of nodes, average hops per path to the remote, interface speed, and processing time. In addition, a variable packet size probing strategy was proposed [22], in which the RTT was used to measure the capacity, from the sending node to each hop along the way, depending on the probe packet sizes. In general, in the error correction phase, the network coding (NC) technique can help minimize the number of retransmissions. Instead of initiating packet retransmissions separately, NC allows the source (master station) to combine multiple native packets into a single coded packet. In the existing studies, the NC was applied in the intermediate nodes. However, as mentioned previously, correcting errors with the minimum number of retransmissions can improve the error rate by using different methods in a different context, as described in [23]. Therefore, in this study, we focused on a specific subcarrier technology [11] with a precisely selected SCS. We recommend the incorporation of this technique to the slave station's IoT remote terminal unit (RTU), to ensure a low rate and relatively low power consumption scenario. Specifically, the number of retransmissions is minimized by using the NC at the source. The proposed protocol can be applied in probe delay mechanisms for multicasting and broadcasting. The main idea of the proposed approach is to initially guarantee that the packets are combined to minimize the number of packet retransmissions. The proposed approach can help reduce the number of retransmissions during the recovery and correction of errors, minimize the probing delay in an NB-IoT MD wireless mesh network, and accelerate the identification, maintenance, or removal of a failed electronic MD in a health care technology framework. The remaining paper is organized as follows. Section 2 formulates and remedies the problem.Section 3 introduces the concept and hypothesis of the proposed methodology, Section 4 explains the accelerated E2E probing protocol. Section 5 proposes the reception/decoding of the proposed probing protocol. The simulation results are discussed in Section 6, and the concluding remarks are presented in Section 7.

2 Problem formulation

The widespread use of NB-IoT based on smart sensors for MDs [24] has helped enhance the quality of medical care, ensure patient satisfaction, and improve the healthcare management framework for MDs. Nevertheless, as connectivity protocols are restricted, no single infrastructure can link all the intelligent entities in smart hospitals [25]. The NB-IoT MD facilitates the realization of this aspect. In the existing literature, a random linear network coding (RLNC) strategy is often associated with a given set of intermediate nodes. In this study, the RLNC is only applied to combine the native packet at the source. The probing of MD using wires is not always practical. Moreover, the use of the internet in a dense wireless mesh network (WMN), between MDs and the master station, cannot always ensure the critical connection in the health context. In this regard, to formulate a proper medical network for a hospital with a reasonable capacity to realize the prompt probing of the MDs and effective control of the MDs, the novel strategy was formulated. In particular, to develop a fast and efficient wireless probe medical network, we established a rapid E2E probing protocol to connect intelligent MDs in smart hospitals based on the NB-IoT MD in the WMN. The reason behind using mesh networks for medical sensors in hospitals is more assured to communicate easily between the device and without interruption. WIFI is widely deployed, but it is neither practical nor secured to connect these devices to WIFI networks through technologies like LORA.And the latency calculated according to different parameters such as average message sizes (AMS) would be better, and it is good to go for medical monitoring usages.We incorporated certain essential parameters to resolve the latency constraint in the healing phase.A continuous monitoring system was developed to control the real-time operating status of MDs for each hospital bed. The main aim was to reduce the time required to track and collect data from all the RTUs sequentially and to obtain the required information by using the RLNC. A hospital, in which different types of medical equipment were required to be scanned within a brief period, from a single source via multi-hop links in a cooperative medical wireless network, was considered. Moreover, the current probing cycle research protocols were compared with the proposed approach, and we discussed the challenges and possible solutions for developing a smart hospital with intelligent devices. In particular, building a particular NB-IoT MD, which connects multiple MDs (slave station) through numerous wireless communication links, can also realize other novel medical applications.We use TDMA code to avoid inter-floor interference in multi-hop medical wireless devices networks for enabling hospital-wide communications.The E2E probing for NB-IoT-MD is thus poised to revolutionize the functioning of the health-care industry.

3 Network model and hypothesis

Consider a WMN, presented in the form of an acyclic graph $G = (V, E)$. Each node $v \in V$ denotes an master station (MS) with a rectangular transmission range of m groups. Each group corresponds to a set of n medical beds on each floor of the hospital.

The hospital has m levels (m groups).

The v neighborhood indicates the collection of the RTU slaves that occupy the range of the E2E probing process. A wireless bidirectional connection exists between v and all adjacent u, $(u, v) \in V$. The smaller number of the hops between the RTU is the distance separating two slaves u and v .The diagonals represent the longest distance in the network between two arbitrary RTUs.

Any remote device may also send data automatically to the MS (typically an alarm). The supervisory control and data acquisition (SCADA) framework is used to realize the control, monitoring,and E2E probing process for RTU slaves. The original information is extracted from the SCADA, which is considered as the source, that is, $SCADA = S$. It is considered that all the packets consist of the same set of vectors from the source, which represents the group size. All the individual group packets are labeled with the same group index. The progressive groups are characterized by group indices, which increase gradually.

The probe packet is being used as an active measurement tool to collect information regarding a medical network parameter of critical interest. The multicast network slave receives, for the first time, the original packet within the network for which the packet is intended. If an intended, RTU does not well receive the original packet, the ARQ mechanism requests retransmission. Using the proposed protocol, each slave can access the radio channel instantaneously to prevent collisions when using the TDMA methodology.

Suppose the cumulative overhead delay for one E2E probing cycle is D_c, and $D_{i.j}$ is the delay experienced by the ith patient, RTU slave, when it is probed to transmit all its packets of the jth room.The E2E probing delay can be expressed as:

$$D_{E2EP} = D_c + \sum_{i=1}^{n} \sum_{j=1}^{m} (D_{i.j}) \tag{1}$$

Consider the scenario shown in Fig. 1. In an NB-IoT network, the SCADA (source) $S \in V$ must send multicast $\sum_{i=1}^{n} \sum_{j=1}^{m} (P_{i.j})$ information packets for E2E probing $n \times m$ RTUs slaves $(RTU_i \in V)$, while minimizing the delay over a system. The device has a traversing delay at each edge of the network. In the case of a medical room, in addition to probing the MD temperatures, it may necessary to test the moisture content, door status, voltage rectifier status, and battery voltage.

An RTU is used as the electronic microcontroller for the monitoring systems, allowing the collection and transfer of the data to a central system from the IoT MDs through the medical room. Each IoT sensor must be setup individually. The primary purpose of the RTU is to provide an interface for the distributed control IoT MDs, supervisory control, and SCADA systems, by sending the telemetry data from these IoT MDs. The use of a single RTU can minimize the installation, management, maintenance, and preparation time in all the patient rooms. The following MDs are considered for the probing task::

- COVID-19 ventilators
- Remote temperature monitoring for vaccines
- Medical data transferring tools
- Air quality sensors
- Drug effectiveness trackers
- Vital signs data capturing devices
- Sleep monitors
- Medication refill reminder devices
- Remote care biometrics scanners
- Sleep and safety tools for infants.

Consider the topology shown in Fig. 2. The hospital consists of several medical beds and m floors. Several medical types of equipment, connected to an RTU, surround each bed, and these devices are termed as slaves. We assume that all the floors have the same number of beds n. .

During the E2E probing, as shown in Fig. 2, the SCADA center interacts with the various RTU slaves by conducting read and write operations. When the E2E test process begins, the SCADA protocol transfers information to the MS through the internet. The MS exchanges data with the remote RTU slave. After the operation completion, a new connection is formed with the next remote RTU slave according to the E2E probing order, and the probing of the other slaves continues. Thereafter, the MS (shown in the left part of Fig. 2) aims to disseminate several packets, denoted as

$P_{1.1}$, $P_{2.1}$,..., $P_{n.1}$,$P_{1.2}$,$P_{2.2}$,..., $P_{n.2}$,...$P_{1.m}$,$P_{2.m}$,..., $P_{n.m}$.

Here $P_{i.j}$ denotes the ith parquet of the jth floor and n is the number of parquet in each level. The k intelligent NB-IoT RTU is in the communication range of the MS and might receive the packets, where $k = n \times m$.

The MS transmits a packet $P_{1.1}$ but only $RTU_{1.1}$ accept it . Later, the MS forwards the packet $P_{2.1}$ but at this time, only $RTU_{2.1}$ correctly receives the packet $P_{2.1}$. Thus, each $RTU_{i.j}$ receives a different packet.

The general operating scenario is as follows: Every $RTU_{i.j}$ that participates in WMN traffic must have a unique unicast address assigned to it. In this context, the unicast transmission works over both UDP and TCP. and is virtually identical over IPv4 and IPv6. In particular, the unicast traffic can easily traverse the NB-IoT RTU. If the destination address does not correspond to the address of the receiving RTU

the $RTU_{i.j}$ iidentified that the $P_{i.j}$ values do not match, and the packet is automatically relayed to the next RTU. The RTU can be used as a receiver or relay simultaneously. In the traditional approach, the lost packets are recovered using

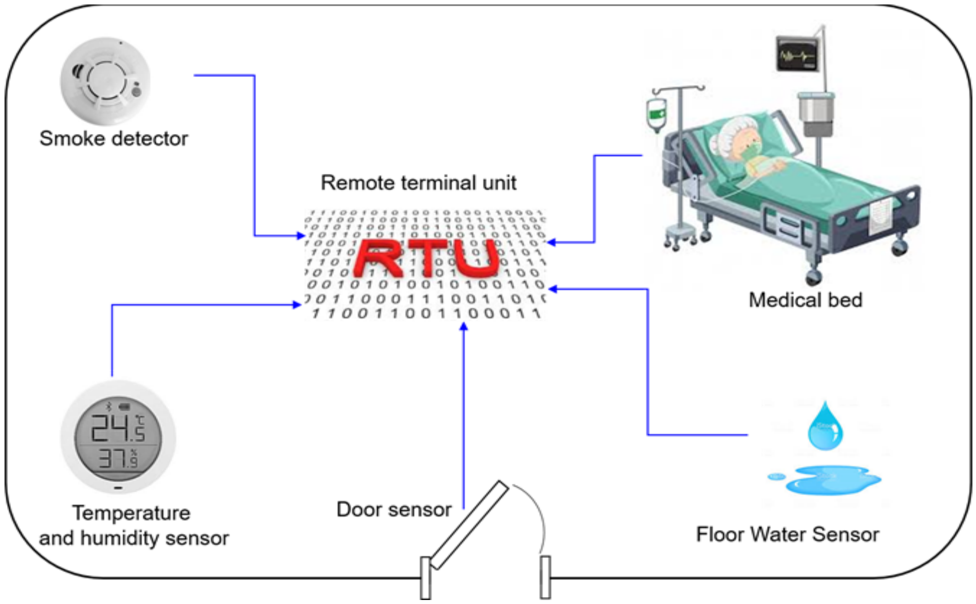


Fig. 1. The RTU offers a core network link for all the linked sensors. Instead of several interfaces, one data transmission device must be established.

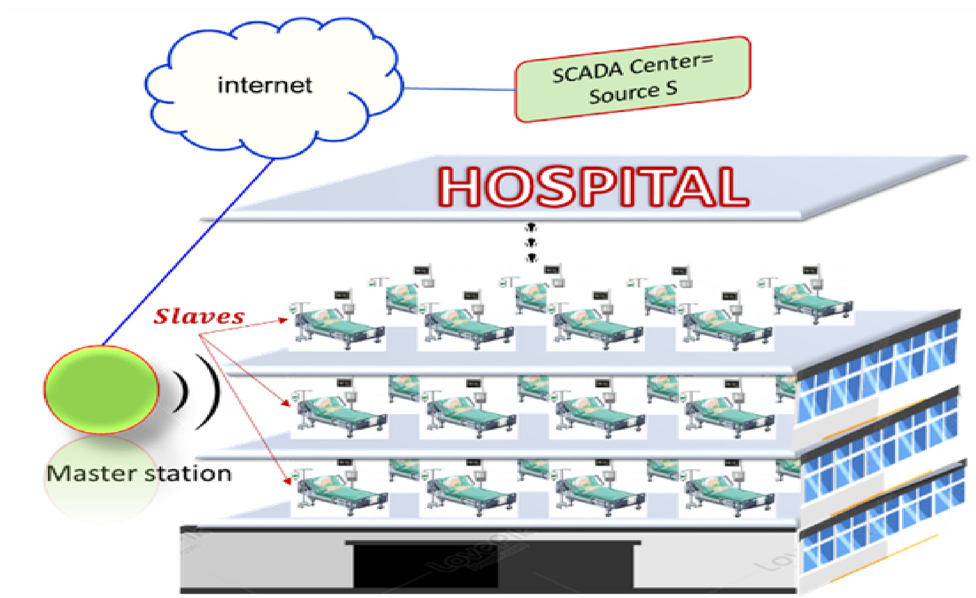


Fig. 2. Medical devices are some of the most critical equipment that needs to be adequately probed, controlled, and monitored. .

retransmissions. In the considered example, the MS retransmits the packets s $\sum_{i=1}^{n}(P_{i.1})$, $\sum_{i=1}^{n}(P_{1.2})$,...,$\sum_{i=1}^{n}(P_{i.m})$.

In the case of the first floor , if these retransmissions are successful, the NB IoT RTU: $RTU_{1.1}$, $RTU_{2.1}$,... and $RTU_{n.1}$ (belonging to the first floor) will receive the missing packets $\sum_{i=1}^{n}(P_{i\neq 1.1})$, $\sum_{i=1}^{n}(P_{i\neq 2.1})$,...,$\sum_{i=1}^{n}(P_{i\neq n.m})$ respectively, where the notations $i \neq 1$, $i \neq 2$, $i \neq n$ denote that the packets $P_{1.1}$, $P_{2.1}$,...,$P_{n.1}$ have not been retransmitted to $RTU_{1.1}$, $RTU_{2.1}$,...,$RTU_{n.1}$, respectively. Thus, even if these $n-1$ retransmissions are successful, a total of $(n-1)\times n$ retransmissions and n transmissions are required for all NB IoT nodes to successfully receive n packets, thereby requiring $n \times n$ transmissions and retransmissions. Thus, for the scenrio shown in Fig.2, for all floors of the hospital, we need a total of $m \times n \times n$ transmissions and retransmissions may be required.

4 Accelerated E2E probing protocol

The duration of an E2E probing cycle in the case of several smart sensors and MDs is often several minutes, which is unacceptable when transmitting time-sensitive data such as that for automatic breathing control in COVID-19 patients. Therefore, we refer to the network scans to identify the vulnerable devices in terms of the required time for the master to individually scan and collect answers for all the MDs (slaves). The packet in a multi-hop mesh network multicast and broadcast must traverse many IoT devices, thereby leading to an excessive delay at the IoT device even when

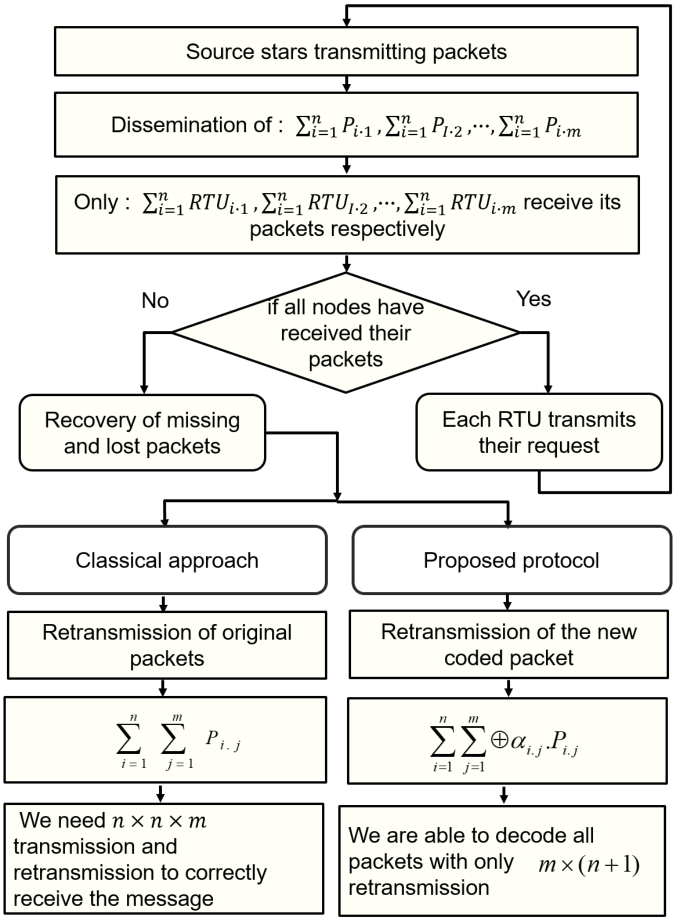


Fig. 3. Phases of operation of the proposed protocol.

they are not the recipients for the multicast or broadcast. The objective is thus to retransmit the combined coded packets during the retransmission phase. The proposed approach merges two or more selected packets to build a new coded output packet C , and the computation is implemented in a Galois field (e.g.,$GF(2^8)$). We consider $n{\times}m$, native packets and one coded packet transmited from one source SCADA (Fig. 2).

$$C(i) = \sum_{i=1}^{n} (\alpha_{i.j} P_{i.j}); j = 1, 2, 3, ..., m \tag{2}$$

We assume that the transmission to all the NB-IoT RTUs subscribes to the destination multicast hospital (address). This multicast functionality is considerably better over IPv6, especially when crossing slaves. The receiving slave uses the short service packet (ACK) to indicate the successful receiving of each packet transmitted on a slave radio channel. If the ACK is not provided, the slave must retransmit the packet as per its retry configuration. The ACK / transmitting method operates independently of any checks at higher stages of the protocol. The suggested phases of the protocol can be summarized as follows (Fig. 3).

In the proposed E2E probing protocol, the MS, instead of retransmitting duplicate packets $\sum_{i=1}^{n} \sum_{j=1}^{m} P_{i.j}$ retransmit the new packet (coded packet) that adds the corresponding coding vector to the outgoing packets in the following general format $\sum_{i=1}^{n} \sum_{j=1}^{m} \oplus \alpha_{i.j}.P_{i.j}.The RTU_{1.1}$ after receiving this packet,it can decode the packet $\sum_{i\neq1}^{n} \sum_{j=1}^{m} P_{i\neq1.j}$,by using the XOR operator[16], between the packet which it has already received, over the new packet. Thus, $RTU_{1.1}$ decode $\sum_{i\neq1}^{n} \sum_{j=1}^{m} P_{i\neq1.j}$ since:

$$\alpha_{1.1}.P_{1.1} \oplus \sum_{i=1}^{n} \sum_{j=1}^{m} \oplus \alpha_{i\neq1.j}.P_{i\neq1.j} \tag{3}$$

In the same way ,$RTU_{2.1}$ decodes $\sum_{i=1}^{n} \sum_{j=1}^{m} P_{i\neq2.j}$ when it receives the new packet $P_{2.1}$ and applies the XOR operator with a packet , which it has already received. Thus,$RTU_{2.1}$ decodes $\sum_{i=1}^{n} \sum_{j=1}^{m} P_{i\neq2.j}$ since:

$$\alpha_{2.1}.P_{2.1} \oplus \sum_{i=1}^{n} \sum_{j=1}^{m} \oplus \alpha_{i\neq2.j}.P_{i\neq2.j} \tag{4}$$

In the same way, the $RTU_{n.m}$ decodes $\sum_{i=1}^{n-1} \sum_{j=1}^{m} P_{i\neq n.j}$ since:

$$\alpha_{n.m}.P_{n.m} \oplus \sum_{i=1}^{n-1} \sum_{j=1}^{m} \oplus \alpha_{i\neq n.j}.P_{i\neq n.j} \tag{5}$$

Consequently, we can recover all packets with only $m \times (n+1)$ retransmission and transmissions. This protocol illustrates an alternative approach of incorporating the NC advantages in the medical topology. The protocol allows the source to transmit $m \times n$ original packets and retransmit one combination packet . If we consider only one floor, the number of retransmissions can be reduced from $n \times n$ to $n + 1$ .Therefore, for $n = 10$, the number of transmissions and retransmissions can be reduced from 100 to 11. Specifically, the number of communications and retransmissions is considerably reduced. Using the aforementioned procedure, we can incorporate many potential gains in the medical network, including enhancing the network capacity, decreasing the latency, and improving the robustness to the network dynamics. Moreover, the rapid protocol can improve the probing cycle by allowing the coded packet to quit the undesired RTU without being decoded.

5 PROPOSED PROBING PROTOCOL (RECEPTION AND DECODING)

Before any transmission, at the source node, a random linear combination of the probe packets relative to each hospital RTU is performed. In this manner, the probe packets are injected into the medical network.

Consider the retransmitted coded output packet as $n{\times}m$probe packets mixed into an MS $\sum_{i=1}^{n} \sum_{j=1}^{m} \oplus \alpha_{i.j} P_{i.j}$ where $\alpha_{i.j}$ denote the coding coefficients, which are critical parameters influencing the network efficiency. For all the floors, the coded packet sent to all the $RTU_{i.j}$ of the first, second ... and mth floors, respectively) must be correctly received. Consider the worst-case scenario and suppose that the packet $P_{1.1}$ is firstl received by the slave $RTU_{n.m}$, although it was expected to be received by $RTU_{1.1}$ and was acquired by $RTU_{1.1}$ from its neighbor. To this end, the packet must be relayed $k-1$ times to ensure that it coincides with its correspondent slave. If the packet $P_{i.j}$ separately arrives at the incorrect slave, it can be rejected by the slave and undergo multi-hops to arrive at the destination. During

TABLE 1
Simulation Parameters

Specifications	Value/Range
Acknowledgment	Off/On
SCS [kHz]	6.25, 12.5, 25 and 50
Form of modulation	QAM/FSK
FEC	Off/On
RF bandwidth of NB-IoT [kHz]	200
Average message length [bytes]	750 and 1500
Number of Hops=H	H=1, H=5
Number of hospital beds	3 to 1000
Bitrate [kbps]	20.83–34.72–41.67–69.44 –104.17–138.89
Processing time [ms]	10

the retransmission, if the packet $\sum_{i=1}^{n}\sum_{j=1}^{m}\oplus\alpha_{i.j}P_{i.j}$ enters the node to follow the transfer of $P_{i.j}$, it is decoded with the existing packet $P_{i.j}$, and the two transmission and retransmission operations continue. The slave tests the checksum of the received packets. Because these checksums are not sequential, the packet with the correct checksum is a packet generated by the MS. If the checksum is wrong, the slave must pause until the additional packet of the encoded packet has been assigned. Each new shipment delivery code updates the packages acquired and inspects the checksum once. Following these two procedures, we assume that neither packet is missing or incorrect until the last packet arrives After the decoding of all the slaves, the response is sent immediately to realize the monitoring and collection of the data pertaining to the MD network activity. The packets to learn the state of the MDs in the network are forwarded separately, thereby avoiding any collision.

6 Results and Discussion

This section presents the results obtained in the simulation conducted using MATLAB. The results obtained using the classical approach and proposed approach are presented, and a comparative analysis is performed to highlight the benefits of the approaches. Consider a hospital involving 10 floors, with each level containing 100 medical beds. The absorptive capacity of this hospital is 1000 patients. We assume that if the guard band is neglected, the RF bandwidth of a physical NB-IoT MD layer is 200 kHz. Multiple settings of the modulation parameters are selected for every SCS, considering the most conveyable and executable values, specifically, 6.25, 12.5, 25, and 50 kHz. These spacing values correspond to a low rate and low electricity consumption of the IoT RTU MD. The time unit is considered to be one second, and it is assumed that the offered network load is variable. Moreover, two average message sizes, specifically, 1500 and 750 bytes, are considered. Table I displays the parameters for the proposed protocol execution.

6.1 Results Obtained Using the Classical and Proposed Protocols

Figs. 4 and 5 show the recovery and correction of the packets by using the classical and proposed approaches, respectively.

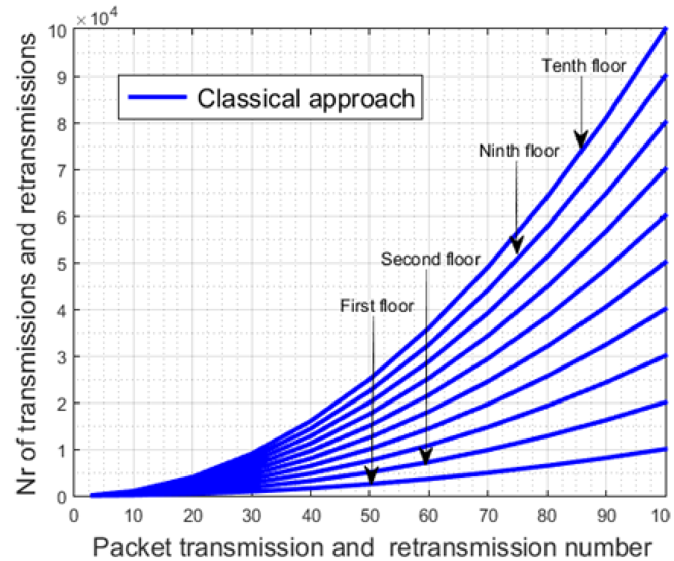


Fig. 4. Number of transmissions and retransmissions for the packets transmitted at different levels of the hospital by using the classical approach.

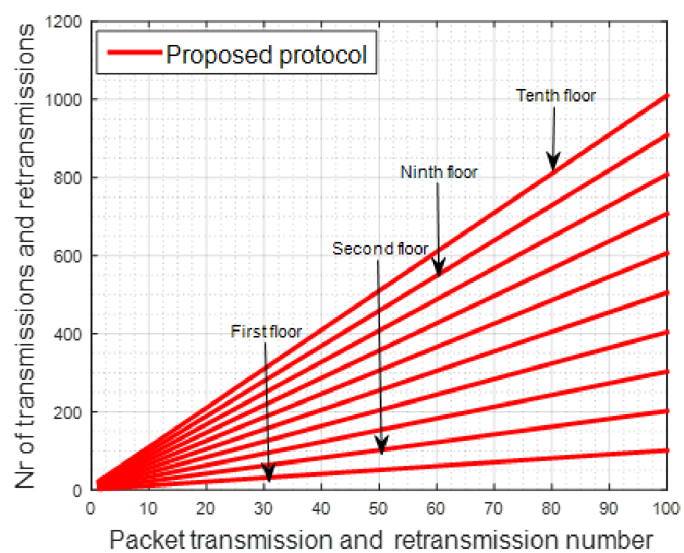


Fig. 5. Number of transmissions and retransmissions for the packets transmitted at different levels of the hospital by using the proposed protocol..

In the classical approach, the missing packets are restored, and thus, a large number of transmissions and retransmissions is required. As shown in Fig. 4, for each floor on each stage, a large number of transmissions and retransmissions is required to recover the lost packets. In contrast, Fig. 5 shows that the number of retransmissions to recover the maximum number of lost packets within a brief period is considerably reduced. Moreover, Fig. 5 shows that the number of transmissions and retransmissions increases linearly with the number of transmitted packets. In summary, the proposed protocol can recover and correct the packets with fewer transmissions and retransmissions compared to those required by the classical approach.

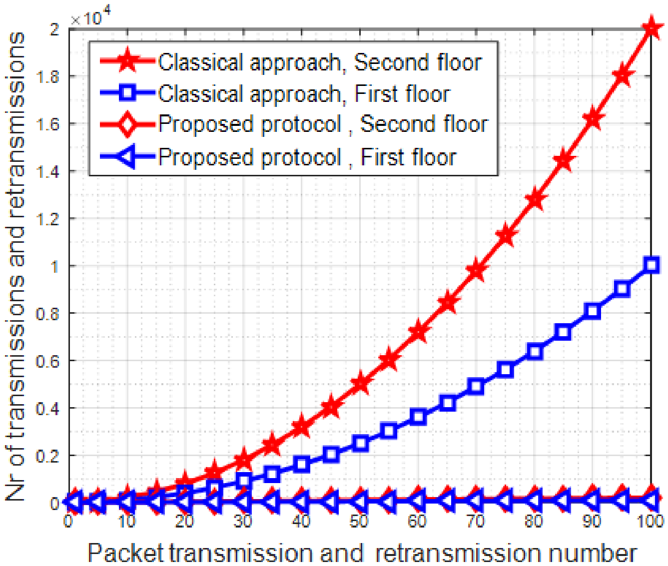


Fig. 6. Comparison of the average time required for the transmissions and retransmissions corresponding to the classical and proposed protocols.

TABLE 2
Comparison of results obtained using the classical and proposed prptocols(second floor)

Number of packet		10	50	100	Figure
Number of transmissions and retransmissions	Classical approach	200	5000	20000	Fig.4
	Proposed protocol	22	102	202	Fig.5
	Comparison (%)	89	97.96	98.99	Fig.6

Fig. 6 compares the results of the number of transmissions and retransmissions corresponding to the two approaches, in the first and second floors of the hospital.

It can be noted that the proposed protocol exhibits a considerably reduced number of retransmission number for recovering the missing and lost packets on the first and second floors. In addition, the proposed protocol helps minimize the E2E probing cycle compared to that for the classical approach. Table II summarizes the results of the comparative analysis.

From the Table II, the proposed protocol's percentage change, derived from Fig. 4 and 5 and compared in Fig.6, able to act 89%, 97.96%, and 98.99% more efficiency and quickly, for the number of packets equal to 10, 50 and 100, compared to classical approach respectively. Therefore, the simulation results indicate that the FPA is a powerful and efficient tool for improving the E2E probing cycle. Fig.7 shows the E2E probes [sec] vs. the number of hospital beds for AMS, CS, without any correction using QAM. Reasonably different limits on broadcasted packet signal parameters result in different modulation rates. The results without using the proposed E2E PP for the End-to-End Probes time versus the number of hospital beds with average message size 1500 bytes and 750 bytes are shown in Fig. 7. The selected SCS is 6.25, 12.5, 25, and 50 kHz, and the number of hops is H = 1, N=3, and the chosen modulation is QAM, especially the 16DEQAM.

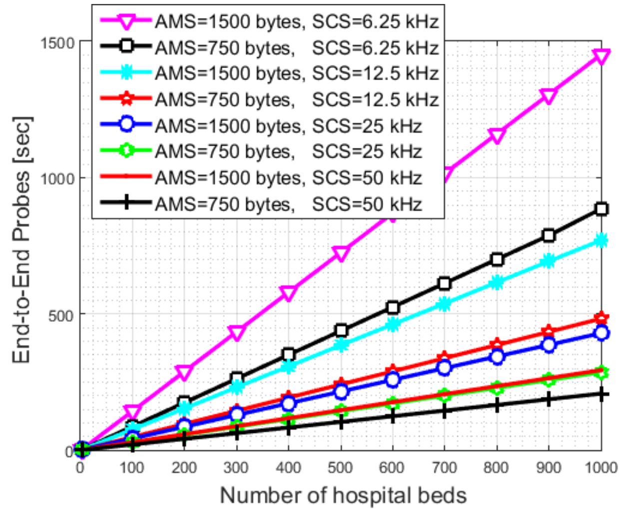


Fig. 7. PPerformance evaluation under different SCS values; N =3, and H = 1, AMS= 750/1500 bytes, and the QAM scheme is applied.

The multiple-subcarrier transmission supports the SCS of 6.25, 12.5, 25, and 50 kHz to define 4,8,16 and 32 contiguous subcarriers, respectively. Consistent with the findings shown in Fig. 4, it can be noted that the E2E probing time is considerably increased. The E2E probing time under SCS=50 kHz is lower than that under SCS=6.25 kHz because of the lower power spectral density. The average message size significantly influences the time required to probe the equipment. Specifically, a large message size retards the probe process, and thus, messages with a suitable size must be used for a specific application. It should be noted that the QAM exhibits a satisfactory performance under normal operating conditions with higher data communication. Fig. 8 shows the E2E probe duration [s] vs. the number of hospital beds for the proposed scheme and that without any correction (without retransmission), using FSK (4CPFSK). Here, AMS = 750 bytes with one hop, and the SCS values are 6.25, 12.5, 25, and 50 kHz.

The comparison of the ascending curves in Fig. 8 indicates that the change in the spacing of the subcarrier leads to a notable improvement in the E2E probing time versus the number of hospital beds. Furthermore, the SCS= 50 kHz has the most beneficial effect in reducing the E2E probing time. For the NB-IoT MD device in WMN, the probing duration decreases with a decrease in the number of slaves and an increase in the SCS. Figs. 9 and 10 illustrate the multi-hop communication through five slaves in the hospital, with AMS=750 bytes Specifically, Fig. 9 shows the results of the E2E probing cycle versus the number of hospital beds different SCS multi-hop wireless mesh networks using QAM.

It can be noted that the E2E probing cycle increases as the number of hospital beds and an average number of hops increase, either together or individually. Fig. 10 shows the evolution of the E2E probing cycle in the classical approach, depending on the number of RTU and hospital beds, to

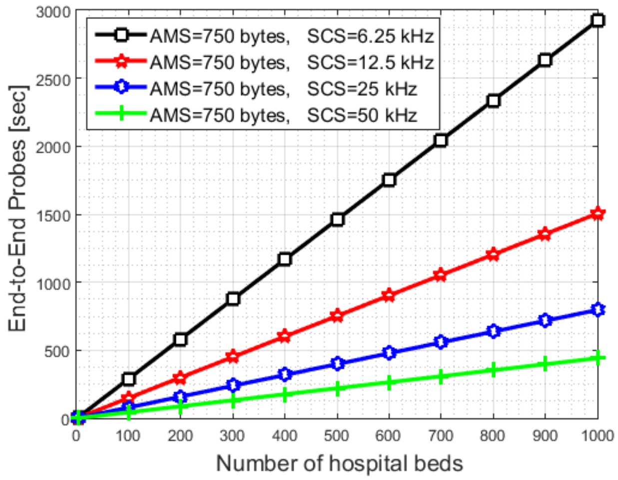


Fig. 8. Comparison and assessment of results under a subcarrier configuration of N = 50, H =1 with AMS= 750 bytes, using FSK.

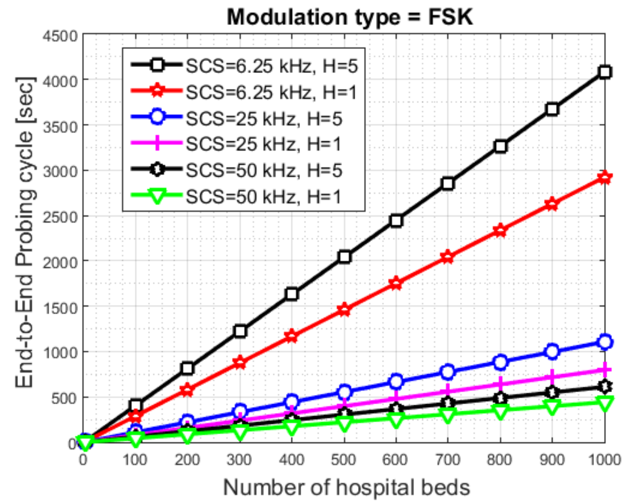


Fig. 10. E2E probing cycle versus the number of hospital beds for SCS 6.25 kHz, 25 kHz, and 50 kHz, using FSK.

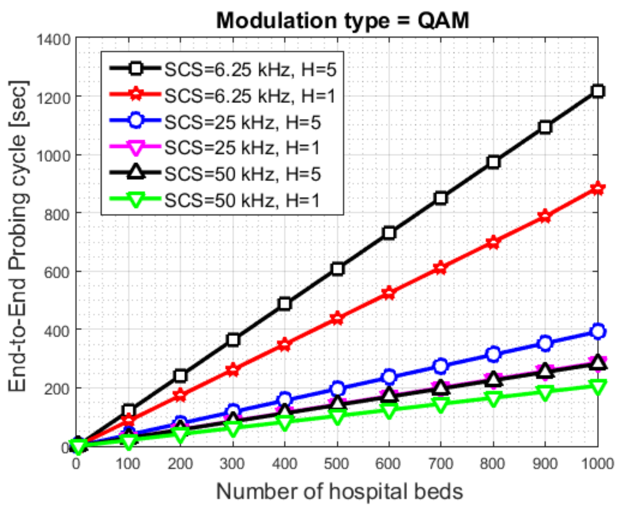


Fig. 9. E2E probing cycle versus the number of hospital beds for SCS 6.25 kHz, 25 kHz, and 50 kHz using QAM.

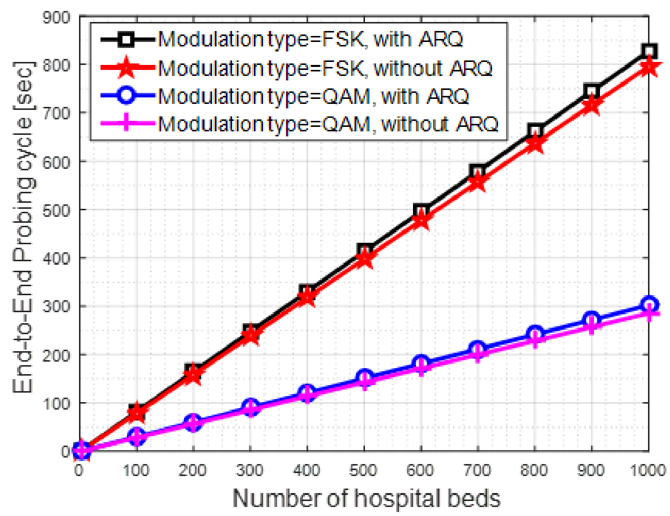


Fig. 11. Probing cycle E2E versus the number of hospital beds for different modulation types and with /without ARQ.

collect the necessary information for the probing using FSK.

The six curves exhibit the same trend for the evolution under the three SCS values for one and five hops. We apply the same parameters as those in Fig. 9 when using the FSK. It can be noted that the FSK modulation requires a longer time compared to that of the QAM to complete the E2E probing cycle. In summary, the comparison between the QAM (linear modulations) and FSK (non-linear modulations) indicates that the E2E probing cycle with FSK is longer, with a reduced symbol rate and higher sensitivity. In comparison, the QAM can be characterized by an ordinarily decreased system gain. Fig. 11 shows the results of the E2E probing cycle versus the number of hospital beds for FSK and QAM modulation schemes and with /without the error correction in terms of the ARQ protocol.

It can be noted that the QAM leads to a considerable improvement in the E2E probing cycle (s) versus the number of slaves. Only a few seconds are required to transmit a single packet between two wireless slaves compared to that in the FSK modulation type. Fig. 12 compares the classical and proposed approaches for the medical IoT system. The former approach is used in various radio protocols for data communication devices, it can transmit both unicast and broadcast frames, and it is widely used when tracking received or transferred frames.

Table 3 compares the classical and proposed approaches in terms of the E2E probing cycle for different numbers of hospital beds (RTUs).

The proposed approach, in the presence of 200, 400, 600, 800 and 1000 RTUs exhibits a time-based improvement of 72%, 75%, 80%, and 85% for SCS=6.25, 12, 25, and 50 kHz, respectively, compared to the corresponding values for the classical approach. These results indicate that the efficiency of the proposed protocol considerably exceeds that of the conventional method.

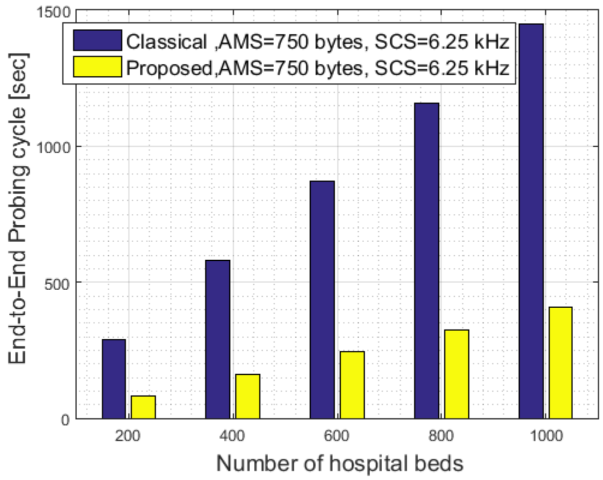


Fig. 12. Comparison between classical and proposed approaches.

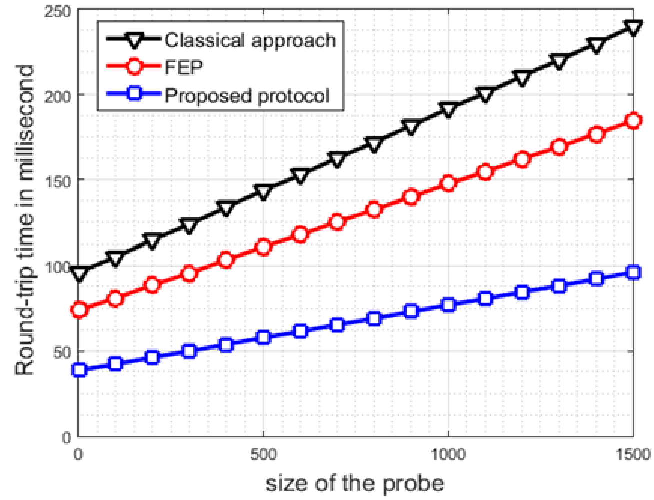


Fig. 13. RTT versus the probe size.

TABLE 3
Comparison of classical and proposed approaches

Number of hospital beds		200	400	600	800	1000
CA	E2E PC	288.9	579.3	869.7	1160.1	1450.5
PP	SC=6.25 kHz	80.89	162.20	243.52	324.83	406.14
CA	E2E PC	153	307.4	461.5	615.6	769.7
PP	SC=12 kHz	38.250	76.850	115.37	153.90	192.42
CA	E2E PC	85.6	171.6	257.6	343.5	429
PP	SC=25 kHz	17.12	34.32	51.52	68.70	85.80
CA	E2E PC	58.4	117.2	175.9	234.7	293.4
PP	SC=50 kHz	8.1760	16.408	24.626	32.858	41.076

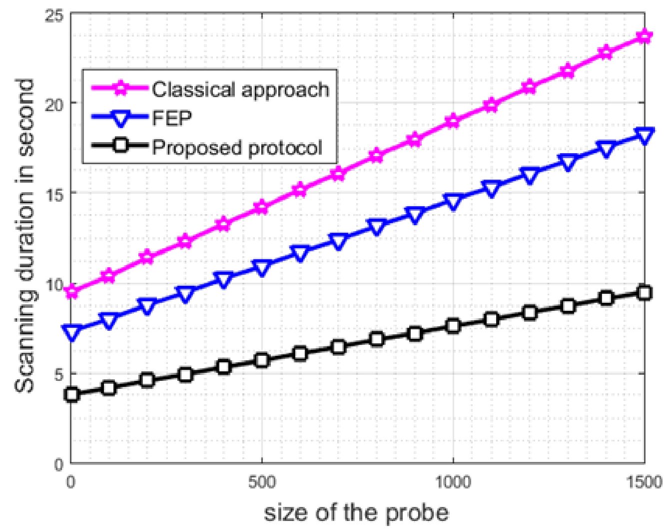


Fig. 14. Scanning duration versus the probe size.

6.2 Optimization of the Proposed Approach

The performance of the proposed approach, as a lightweight method to realize the efficient sampling of heterogeneous IoT networks [16], was attempted to be optimized. The 100-node and H=1 subnetworks can be considered to be a group (for example, for the first floor).

Fig. 13 presents the results for the first subnetwork of the model presented in Fig. 2, for the RTT [s] vs. the size of the probes (0–1500 bytes).

It can be noted that the proposed protocol considerably reduces the time requested by a medical network traversal from the first medical room to the last room on the first floor (100 RTUs), back the first room. This configuration outperforms the other considered configurations. Fig. 14 shows the scanning duration on the second floor vs. the probe information size varies (0–1500 bytes).

It can be noted that the proposed scheme efficiently reduces the overall scanning duration for all the probe sizes. Table IV presents the results for the performance enhancement. It can be noted that the percentage gain in the FEP and PP was approximately 33% and 60% higher than that for the CA, respectively. Consequently, for N=100, the speed of the PP was 60% and 33% higher than that for the CA and FEP, respectively. The simulation results suggest that the FPA is an efficient and useful method to boost the polling process.

7 Conclusion

This paper proposes a rapid and efficient E2E probing protocol for NB-IoT MDs based on the RLNC technique to optimize the probing time. The proposed approach can recover and correct the missing and lost packets, thereby minimizing the number of retransmission. The comparison of the proposed protocol with recent probing procedures

TABLE 4
Performance for 100 medical rooms when using a probe payload length of 32, 128,512, and 1024 bytes.

Size of the probe in bytes		32	128	512	1024	Figures
CA	RTT	99	108	145	194	
FEP	in milli-	76.23	83.16	111.65	149.38	Fig12
PP	second	39.60	43.20	58.00	77.60	
CA	Scanning	9.5	10.7	14.3	19.2	
FEP	duration	7.315	8.239	11.011	14.784	Fig.13
PP	in second	3.800	4.28	5.720	7.680	

demonstrated the associated high flexibility rates and rapid transmission of the packets in this approach. The new scheme, based on several basic parameters characterizing the medical network performance, demonstrated complete reliability. Therefore, as opposed to the traditional approaches, the proposed protocol can be effectively deployed on the existing medical platforms, such as those for COVID-19. Moreover, the proposed method can help reduce the network traffic to transfer the training data without a significant negative impact on the prediction accuracy. Future work will be focused on executing other protocols suitable for other parameters affecting the complete probing cycle.

REFERENCES

[1] S. Barlas. , "FDA flags inconsistent hospital reporting of medical device problems, "Pharmacy and Therapeutics, vol.42, no.2, pp.97–115, Feb.2017.

[2] H. Elayan, R. M. Shubair, A. Kiourti, "Wireless sensors for medical applications: Current status and future challenges," in Proc.11th European Conference on Antennas and Propagation (EUCAP), Paris, France, 2017, pp. 2478-2482.

[3] A.Kiourti, K.A. Psathas, KS.Nikita, "Implantable and ingestible medical devices with wireless telemetry functionalities: a review of status and challenges," Bio electromagnetics, vol.35, no.1, pp.1–15, January 2014.

[4] A. Al-Fuqaha, M.Guizani, M. Mohammadi, M. Aledhari, and M. Ayyash, "Internet of Things: A survey on enabling technologies, protocols, and applications," IEEE Commun. SurveysTuts.,vol.17,no.4,pp. 2347–2376, 4th Quart., 2015.

[5] J. Lin, W. Yu, N. Zhang, X. Yang, H. Zhang, and W. Zhao, "A survey on Internet of Things: Architecture, enabling technologies, security and privacy, and applications," IEEE Internet Things J., vol. 4, no. 5, pp. 1125–1142, Oct. 2017.

[6] A. Gatouillat, Y. Badr, B. Massot and E. Sejdić, "Internet of Medical Things: A Review of Recent Contributions Dealing With Cyber-Physical Systems in Medicine," in IEEE Internet of Things Journal, vol. 5, no. 5, pp. 3810-3822, Oct. 2018, doi: 10.1109/JIOT.2018.2849014.

[7] M. Chen, Y. Miao, Y. Hao, K. Hwang, "Narrow Band Internet of Things," IEEE Access, vol. 5, pp. 20557-20577, 2017.

[8] J. Chen, K. Hu, Q. Wang, Y. Sun, Z. Shi and S. He, "Narrowband Internet of Things: Implementations and Applications," in IEEE Internet of Things Journal, vol. 4, no. 6, pp. 2309-2314, Dec. 2017, doi: 10.1109/JIOT.2017.2764475.

[9] S. M. R. Islam, D. Kwak, M. H. Kabir, M. Hossain, K. Kwak, "The Internet of Things for Health Care: A Comprehensive Survey," in IEEE Access, vol. 3, pp. 678-708, 2015.

[10] Wu, Fan; Wu, Taiyang; Yuce, Mehmet R , "An Internet-of-Things (IoT) Network System for Connected Safety and Health Monitoring Applications." Sensors vol.19, no. 1, pp. 21, Jan 2019.

[11] EM. Ar-Reyouchi, I. Maslouhi, K. Ghoumid, "A new fast polling algorithm in wireless mesh network for narrowband Internet of Things," Telecommunication Systems , vol.74, no.3 ,pp.405–410, July 2020.

[12] Y.Wang, Z Wu,"A Coexistence Analysis Method to Apply ACLR and ACS between NB-IoT and LTE for Stand-Alone Case," In Proc. Sixth International Conference on Instrumentation & Measurement, Computer, Communication and Control (IMCCC).Harbin, Chine,pp.375- 379,2016.

[13] Zhang X., Zhang M., Meng F., Qiao Y., Xu S., Hour S.H. A Low-Power Wide-Area Network Information Monitoring System by Combining NB-IoT and LoRa. IEEE Internet Things J. 2018 doi: 10.1109/JIOT.2018.2847702..

[14] H. Zhang, J. Li, B. Wen, Y. Xun and J. Liu, "Connecting Intelligent Things in Smart Hospitals Using NB-IoT," in IEEE Internet of Things Journal, vol. 5, no. 3, pp. 1550-1560, June 2018.

[15] M. Chafii, F. Bader and J. Palicot, "SC-FDMA with index modulation for M2M and IoT uplink applications," 2018 IEEE Wireless Communications and Networking Conference (WCNC), Barcelona, 2018, pp. 1-5, doi: 10.1109/WCNC.2018.8377028..

[16] E. Ar-reyouchi, Y. Chatei, Y, K. Ghoumid, M. Hammouti, B. Hajji, " Efficient coding techniques algorithm for cluster-heads communication in wireless sensor networks," International Journal of Electronics and Communications (AEU), vol.82, pp.294–304.2017

[17] S.Rattal, E. Ar-Reyouchi, "An effective practical method for narrowband wireless mesh networks performance," SN Applied Sciences, vol.1, no.12, 2019

[18] Y. Chatei, M. Hammouti, E.Ar-reyouchi, K.Ghoumid, "Downlink and Uplink Message Size Impact on Round Trip Time Metric in Multi-Hop Wireless Mesh Networks," International Journal of Advanced Computer Science and Applications (IJACSA), vol.8, no.3, pp.223-229, 2017. https://doi.org/10.14569/ijacsa.2017.080332.

[19] T. Xu, I. Darwazeh, "Non-Orthogonal Narrowband Internet of Things: A Design for Saving Bandwidth and Doubling the Number of Connected Devices," IEEE Internet Things J., pp. 1–1, 2018

[20] L. Metongnon and R. Sadre, "Fast and efficient probing of heterogeneous IoT networks," International Journal of Network Management, vol. 28, no. 1, pp. 1–19, 2017

[21] Y. Chatei, K. Ghoumid ,E.M. Ar-reyouchi, "Narrow-band channel spacing frequencies metric in one-hop wireless mesh networks," 2nd International Conference on Communication and Electronics Systems (ICCES), Coimbatore, 2017, pp. 296-301, doi: 10.1109/CESYS.2017.8321284.

[22] M. Turrubiartes, D. Torres, M. Angulo and D. Munoz, "Analysis of IP network path capacity estimation using a variable packet size method," 15th International Conference on Electronics, Communications and Computers (CONIELECOMP'05), Puebla, Mexico, 2005, pp. 177-182, doi: 10.1109/CONIEL.2005.20.

[23] M. Mohammadi, A. Al-Fuqaha, "Exploiting the Spatio-Temporal Patterns in IoT Data to Establish a Dynamic Ensemble of Distributed Learners," IEEE ACCESS, vol. 6, pp. 63316–63328, October 2018.

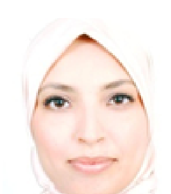
[24] H. Zhang, J. Li, B. Wen, Y. Xun and J. Liu, "Connecting Intelligent Things in Smart Hospitals Using NB-IoT," in IEEE Internet of Things Journal, vol. 5, no. 3, pp. 1550-1560, June 2018, doi: 10.1109/JIOT.2018.2792423.

[25] L. Catarinucci et al., "An IoT-aware architecture for smart healthcare systems", IEEE Internet Things J., vol. 2, no. 6, pp. 515-526, Dec. 2015.

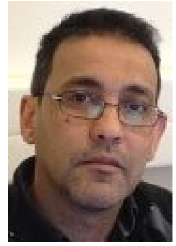
El Miloud Ar-Reyouchi received his Ph.D. in Telecommunication and Computer Engineering from Abdelmalek Essaadi University Tetouan Morocco and his Engineer degree from INPT institute national of telecommunication RABAT Morocco, MS in industrial computer and his CPD / DEA degree in automatic and industrial computer from ETS computer engineering, Department Computer Science and Control, Madrid Spain. His research interest includes telecommunication, broadcasting TV/FM, engineering automatic systems, mobile wireless net-work, antennas & propagation. He is currently Service regional head of Radio & Television Broadcast Station of SNRT (Société Nationale de Radi-diffusion et de Télévision) Morocco. .

Kamal Ghoumid received his Ph.D. degree from the 'Institut Mines-Télécom, Télécom Sud-Paris', Evry, France, and 'Institute FEMTO-ST' of the Franche-Comté University (Besaçon, France), in 2008. He previously graduated as a specializing Master in 'Technics of Radio communications', also got his DEA (Master) 'Communication Systems' of Paris-Est University (Paris, France). He has worked as a postdoctoral researcher at Jean Lamour Institute of Henri Poincaré University (Nancy, France), during 2008-2009, and at the Institut FEMTO-ST of the Franche-Comté University, Besançon. Currently, he is a professor in ENSAO (Ecole Nationale des Sciences Appliquées d'Oujda) - Mohammed First University, Morocco. His research interests are mainly in a mobile wireless network, Signal processing, and optical information processing, Radio over Fiber, Internet of Things, he has also the experience in research areas of digital communications.

Doha Ar-Reyouchi received an MD from, Faculty of Medicine and Pharmacy, Mohammed First University. She is completing general surgery residency, Department of plastic and reconstructive surgery, CHU University Hospital Center, Oujda, Morocco



Salma Rattal received her Ph.D. degree in Telecommunication from Hassan II University, Casablanca, Morocco. She previously graduated as a specializing Master in Telecommunication and a network of UCD, Chouaïb Doukkali University, El Jadida. She has worked as a postdoctoral researcher at the University of Hassan II of Casablanca • Electrical Engineering Department. At the laboratory of SNRT, Currently, she is a professor at the Moroccan School of Engineering Sciences.



Réda Yahiaoui obtained his engineering degree in Electronics at USTHB-Algeria in 1993. He received his Diploma of Advanced Studies (DEA) in Electronics, Sensors and Integrated Circuits - Microwave and Fast Electronics Option in 1998, and his doctorate in engineering sciences in 2002, at the University of Paris-XI, Orsay. Since September 2005, he has been a lecturer at the University of Franche Comté in the Electronics department of the UFR-ST of Besançon for the teaching mission, he was attached for the research mission to the MN2S department of the 'FEMTO-ST Institute, until April 2019 when he joined the LNIT laboratory. He is interested in both the development of BioMEMS devices for biomedical applications, in particular vibrating MEMS for the detection of bacteria in healthcare establishments, and in intelligent monitoring systems connected remotely, capable of monitoring health, preventing illnesses and falls at home or in institutions for the elderly.

Omar Elmazria is a Full Professor (Exceptional Class) at Université de Lorraine (UL) within Institut Jean Lamour (IJL UMR 7198) for research and Polytech Nancy for teaching. He is also an emeritus member of the IUF (Institut Universitaire de France) and was guest Professor at several Universities around the world (SFU, Canada; IoA, Chinees Academy of Sciences; UCF, USA). His current research focuses on SAW devices for communication systems and sensing applications. He is the author and co-author of more than 180 international scientific articles, 4 international patents issued, and more than 120 communications in international conferences. He is senior member of IEEE society and a member of several technical committee programs including IEEE International Ultrasonic Symposium and IEEE MTT-TC26 RFID, Wireless Sensor and IoT. In 2017, he receives URSI-France medal from the International Union of Radio Science.