Analysis of the New Method for Assessing the Total Network Capacity of Wireless Mesh Networks for IoT Devices

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Abstract

Measuring and computing the total network capacity (TNC) is a task that sounds simple, but in reality, it can be a remarkably challenging and quite complex problem. This paper gives a quick performance method evaluating the TNC in multi-hop wireless mesh networks (WMN). It focuses simultaneously on two key operating metrics the total Internet protocol (IP) network capacity (TIPNC) and the total application network capacity (TANC) versus the average message time (AMS) and Average hops per path to a remote. It also analyzes how basic settings such as forward error correction (FEC) and acknowledgments (ACK) affect the overall network capacity (NC) under different operating conditions. The experimental results obtained from the proposed method gave a quick and easy idea of the possible capacity in the WMNs for the Internet of things (IoT) devices as well as the advantages of measuring and computing the TNC method over conventional methods. Both calculating and measuring comparisons show that the technique performs with different rates of success in various settings. Besides, these results can be useful, principally, during the conception of a WMN.

Keywords: Wireless mesh network, Network capacity, Average message size, Forward error correction

1 Introduction

With fast expanding numbers of WMNs [1] available for IoT [2] applications, developers need to understand how these networks differ concerning the use cases and expected performance. The testing focused on device behavior and the impact of AMS, FEC, and ACK [3] on NC, TIPNC, and TANC. The NC can be enhanced by growing the number of gateways if they are sufficiently spaced [4] from each other. In effect, the NC is constrained by the activity inside a bottleneck zone around [5] the gateway.

A significant surge in demand for TIPNC / TANC has spread rapidly in recent years and has started to widely invade the industrial Internet of things (IIoT) [6]. This turnout has been caused by an ascendant demand from IoT devices and consumers with an exceptional and high ambition for real-time access to massive amounts of data services. To confront this insatiable consumer traffic demand, and operators [7] are obliged to enlarge NC. In the context of WMNs, NC (in bytes per second) can be considered as the intricate measurement of the maximum quantity of data that may be conveyed between network places over a network path. Because of the number of intertwined measurement variables and complicated scenarios, the actual NC metric is rarely found with a precise measure. In [8], the authors address the problem of calculating the transport capacity of WMNs destined to the Internet. Capacity is also known as data rate or as throughput.

Many works adopt channel parameters for evaluating calculate NC in wireless sensor networks (WSN) [9] and WMN, such as) [10-13]. However, to the best of our knowledge and belief, none of them has proposed solutions that allow the FEC and the ACK to influence the assessment of the capacity in a WMN.

Network capacity planning is a critical approach of conveyable network architecture planning to guarantee an efficiency network, and it has an increased capacity [14] to meet future needs. In [15], the authors propose algorithms to improve NC through well-designed channel assignments in multi-hop wireless networks. WMNs regularly connect bounds on the maximal achievable data rate to spatial reuse constraints and MAC-layer impacts. In WMNs, where all remote nodes employ the identical physical channel (such as IEEE 802.11 [16]), the TNC capacity is certainly conditional on the coverage area of each wireless remote node, since a packet transmission by a node efficiently precludes any transmissions, happening at about the same time, by neighboring IoT nodes (within its interference range).

Managing performance NC depends on several essential parameters, specifically, among which we may cite the following: Rate at which handsets enter and leave a covered cell site area, average message size [17], average hops per path, modulation (type and rate), subscriber services, FEC and ACK, these parameters

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can also affect Trip Time Metric in multi-hop WMN as in [18]. Also, the number of nodes affects NC as in dense wireless sensor networks (DWSNs), which is one of the fundamental parameters [19] as well as the maximizing lifetime [20].

Generally, every wireless network employing narrowband radios requires “capacity-aware design,” In [21] the authors analyzed and defined the transport capacity of wireless networks. They send packets from node to node in a multi-hop mode until they reach their final destination. While the transmission capacity notion, as defined in [22] for theses, both slightly relaxed capacity notions were mainly possible.

The author of [23] studied the behavior of complementary definitions of the WMN capacity face to several parameters of WMN, highlighting the unfairness among traffic. In [24], the researchers studied the capacity of the mesh network using three different technologies. However, they had not taken into account any necessary Error Correction, namely Automatic Repeat reQuest (ARQ) and FEC, which are one of the essential techniques for building WMN. In this paper, the analyzed and measured TNC of WMNs using FEC, and ACK [25] can rapidly give the network performance

The IoT carriers are forced to grow NC to accommodate exploiters of IoT requests for high-bandwidth services. Nowadays, NC is required to handle increased IoT devices and supplementary services. For a similar reason, the total achievable network capacity is also a function of the IoT devices' density, which implicitly determines the average number of one-hop neighbors. In the paper [4], the authors analyze the capacity of wireless networks. With randomly located nodes considering two types of networks, arbitrary, and random networks. The Network Capacity based router selection (NCRS) has presented in [26] can rely on both the routing layer and MAC 802.11 protocol to satisfy the quality of service (QoS) requirements. This method can be used for a simplistic overview of remote devices performance, which can be the IoT devices and sensors network. These nodes are often found in the isolated areas; fconsequently, they could prolong significantly to prolong the stable period of Fog supported networks by maintaining balanced energy consumption as in [27].

In this work, we analyze the NC of WMNs, which is characterized by reliable services, as well as enhancing NC. We assume that each node is located in the middle of the region of an area, and it can transmit at bits per second over a shared wireless channel. Packets are sent from station to station in a multi-hop mode until they reach their single final destination (remote station). They can be buffered at intermediate stations while awaiting transmission. To simplify the tasks of the nodes, the medium access mode to be used is a TDMA, as applied in [17]. TDMA is a successful method for avoiding packet collisions. However, time slot distribution must be realized to use TDMA. This paper tackles the problem of evaluating and determining the exact NC of a WMN. The proposed method study the behavior of TNC face to several parameters: Average hops per path, Interface speed (IS), Operating Mode, Radio protocol, ACK, Channel spacing [kHz], Modulation type, Modulation rate [kbps] and FEC.

The paper is organized as follows. Section 2 presents wireless mesh networks and the effect of FEC and ACKs in IoT networks. Section 3 discusses network capacity. Section 4 gives an overview of the system model. Section 5 presents contributions on some measurements and numerical results obtained for the described model. Section 6 discusses limitations, strengths from the methodological point of view of other different works, as well as also explaining the proposed approach is new, and how it is inserted in the context of existing methods. Section 7 provides conclusions from the analysis results

2 Network

2.1 Wireless Mesh Network (WMN)

WMN is a wireless local area network (WLAN) that employs one or more decentralized connection IoT devices: complete mesh topology or partial mesh topology. In a full mesh topology, each network IoT device is connected directly to each of the other IoT devices. In a partial mesh topology, some IoT devices are connected to all the others, but others are only connected to those IoT devices with which they interchange the most data. In WMN, all IoT devices can access each other randomly and spontaneously, and each network IoT device can forward data to the next IoT device. The networking infrastructure is decentralized and simplified because each IoT device only needs to transmit as far as the information of the upcoming IoT device. Wireless mesh networking could permit users to live in remote areas operating in rural neighborhoods to connect their networks for available IoT connectivity.

In wireless mesh-type networks, all IoT devices can access each other arbitrarily and spontaneously. WMNs can also accomplice polling or report-by-exception applications.

Each link $e_{i,j}$ between IoT devices (i and j) could be noisy, so the information in the packets also needs to be encoded to verify and correct the errors. In this paper, we analyze FEC, and ACK approaches, a class of time-diversity techniques, in the context of the IoT network at the link and transport layers.

2.2 Effect of FEC and Acknowledgments (ACKs) in IoT network

FEC is a beneficial technique to understate IoT wireless channel weakness. The transmitter subjoins some redundant data into its messages, and this redundancy permits the receiver to detect and correct the erroneous packet. The improvement comes at the expense of the data transfer rate concerning each IoT devices.

IoT Device data rate = Modulation rate x FEC ratio

The above formula shows that the lower the FEC ratio, the better the ability of error correction and the lower the IoT device data rate.

ACK is a setting, which requires additional bandwidth to repeat corrupted frames. Each packet transmitted over an IoT wireless channel from IoT device has to be acknowledged by the receiving IoT device, using the short service packet (ACK) to announce that it has received the packet correctly. If ACK is not received, the IoT device retransmits the packet depending on its set of new attempts.

When the packet from the IoT device (transmitter) is successfully received by IoT device (receiver), it no needs to reconstruct any dropped, lost, and missing packets at the receiver. Consequently, there is no requirement to receive ACK from the receiving IoT device, i.e., the packet is transmitted only once, and it is not re-iterated. We note that the acknowledgment/retransmission scheme is an integrated part of the radio protocol and works individually of any new attempts at higher protocol levels (e.g., TCP or IoT devices application protocol).

3 Network Capacity (NC)

Consider a WMN using a single radio channel shared among all routers, which are assumed static. We distinguish the NC, defined as the maximum capacity in bytes per second (includes IP packet overhead) of a link. Also, we consider the network path to convey data from source (SCADA center node) in the network to the destination can be used as the remote station (RS) via intermediate nodes.

In the context of the Internet of Things (IoT), a better network-wide capacity is necessary for providing a better quality of service to a more significant number of users.

In this paper, the TNC in bytes per second (includes IP packet overhead) is defined as the resulting number mentions to the total amount in the ideally designed IoT device network. Notwithstanding, that figure can be completed only when there is a considerable portion of the communication load among the IoT remotes themselves.

When all control messages have ultimately reached the SCADA center over the same links employing the same radio-channel, any calculation of TNC loses its sense. This problem can be eliminated by adding additional channels or bypass dominant IoT devices using more radio hops. Usually, every network of devices using narrowband radios demands a capacity-aware layout.

Consider the network in Figure 1, which consists of three $(n = 3)$ wireless IoT devices in coverages areas. IoT device 1 sends its packets to IoT device 2, and, thus, the link $e_{1,2}$ has to be able to forward traffic. IoT device 2 starts forwarding its packets to IoT device 3, IoT device 1 can communicate with outer 2; IoT device 3 can also interact with IoT device 2 using the link $e_{2,3}$. However, IoT devices 1 and 3 cannot communicate with each other, but their signals can interfere with IoT device 2.

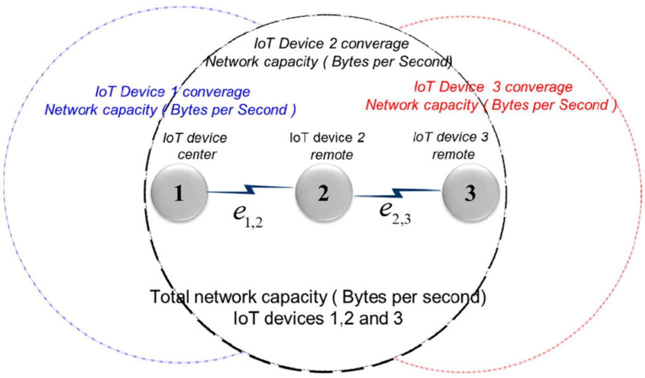

Figure 1. The basic concept of the Total Network Capacity in wireless IoT devices

Digital radio has developed ways in which more than one conversion of information to the data center can be accommodated (multiplexed) inside the same physical radio channel, for achieving this, we use the TDMA method. It must be noted that in that case, TNC. is dependent on the transmission range of each IoT node

So that the collisions cannot be excluded entirely, hence a collision-solving system must be a complete part of the protocol in the radio channel.

Multi radio WMNs provide several advantages, such as increased NC. Whenever the traffic rises over a specific limit, the number of collisions augments considerably, decreasing the instant NC well below normal situation.

4 System Model

In this paper, the fixed infrastructure of the WMN is represented by an acyclic directed graph $G = (V, E)$ with an IoT node-set $V = \{v_1, ..., v_n\}$ representing mesh points and an edge set E . The directed edge connecting the IoT device v_i to the IoT device v_j is denoted by $e_{i,j}$.

We assume that all the IoT devices are synchronized. Each edge $e_{i,j}$ has a capacity $C_{i,j}$ (bits/sec), meaning that a packet of L bits is transmitted in at least $L / C_{i,j}$

seconds. We consider that, for each link $e_{i,j}$, the maximum transmission delay of a packet of L bits is known and equal to $L/C_{i,j}+T_{i,j}$, where $T_{i,j}$ is the service delay over the links $e_{i,j}$.

Figure 2 shows the SCADA center and a chain of n IoT nodes, which respectively generate and forward traffic to the RS.

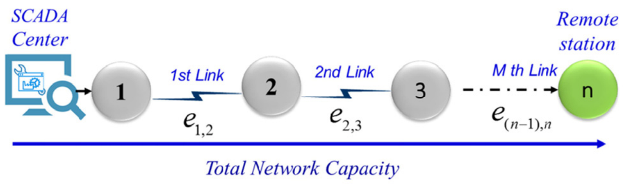

Figure 2. Total Network Capacity with M links, a chain of n nodes generating and forwarding data to a remote station.

SCADA center sends control information to all IoT devices. SCADA application typically uses a specific address for such control information. The receiving IoT node 2 (directly connected to the IoT device 1 (one radio hop), converts such message to a customized IP broadcast and sends it to IoT device 3 over one IoT device 2 (two radio hops) respectively to all device's units within the network. Each link in the chain is constrained to send only when the other relationships in its vicinity are inactive.

Assume that each IoT device receives traffic to be forwarded to the RS and that each IoT device can only receive packets from its immediate neighbors. The traffic that has to be forwarded by each link is computed. It is clear from the picture that nodes closer to the RS have to forward more traffic than nodes farther. The RS is connected to the SCADA center through n IoT nodes, with the last one is considered as an RS.

The packet must be completely received before being forwarded to the next IoT device. Consider D as the total delay for sending N packets crossing n nodes over M links (pipelining delay) that we can give it in the form [28]:

$$D = Propagation\ delay + Transmission\ Delay + Pipelining\ delay$$

$$D = D_p + N * D_{TP} + (M-1) * D_{TP} \quad \textbf{(1)}$$

were D_{TP} = transmission time of the packet. Each packet contains L bits of data and a header of size H bits with total packet size $L+H$ bits.

$D_p = \frac{d_{total}}{V_p}$, d_{total} is the total distance between the SCADA center and RS and V_p is the propagation speed over the specific medium.

The message transmission of S bits we need S/L packets, therefore the time to transmit the message over M links is

$$D = \frac{d_{total}}{V_p} + \frac{S}{L}(\frac{L+H}{R}) + (M-1)(\frac{L+H}{R}) \quad \textbf{(2)}$$

where R is data rate.

In this network, there is one source node (SCADA center) and one destination node (remote station). The source node does not have any incoming edges, and a destination node does not have any outgoing edges. SCADA center has a message for monitoring the RS system as in [29].

Consider that the TNC C_{TNC} is the relationship between useful data trafficked which is the user's data sizes without any headers (IP, TCP, UDP…) trafficked by all IoT devices and the total time takes them to do it, so we have:

$$C_{TNC} = \frac{n \times L}{\sum_{i=1}^{n} T_i} \quad \textbf{(3)}$$

where n is the number of connected IoT devices and T_i is the average time it takes each one to traffic L bytes of payload.

We assume that C_i is the capacity, which every node would obtain and be connected to another device via particular and dedicated channels (links) in a mesh topology.

Rewriting the equation (3), we get:

$$C_{TNC} = \frac{1}{\frac{1}{n}\sum_{i=1}^{n}\frac{T_i}{L}} \quad \textbf{(4)}$$

which is equivalent to:

$$C_{TNC} = \frac{1}{\sum_{i=1}^{n}\frac{1}{n}\frac{1}{C_i}} \quad \textbf{(5)}$$

This last result represents the TNC, assuming that all connected users are reporting as much as possible.

TNC assumes that all radios in the network operate on the same RF channel. It is important to note that the TNC in bytes per second (includes IP packet overhead) is the resulting number refers to the maximum number in the optimally designed IoT devices network. While the TANC is TNC in bytes per second, but no IP packet overhead is included.

The following Table 1 lists the technical parameters selected for the used topology.

We assume that there is only one SCADA center and one RS in the network. Furthermore, every IoT node is capable of creating, receiving, or transmitting data over a communications channel. The topology illustrated in Figure 2 is respected for the simulation with $n = 9$.

Table 1. Characteristics of Topology

Settings	Status /Mode /Type/Value
Average message size (bytes)	0-1500
Processing time (msec)	20
Interface speed	ETH TCP/IP
Modulation	QAM
FEC, ACK.	3/4 /Off
Nodes number	9
Channel spacing	25 kHz
The output power of each device	1-10 watts

5 Results

We measure the evolution of TIPNC (inserts IP packet overhead) with Total application network capacity (no inserts IP packet overhead) face several parameters such as:

- Average hops per path
- Interface speed.
- Operating Mode
- Radio protocol.
- ACK, Channel spacing [kHz].
- Modulation type.
- Modulation rate [kbps].
- FEC.
- TIPNC.
- TANC.

This section describes the results of the experiments. The presented measurements show how TANC varies depending on the several Message sizes for fixed according to the modulation type (QAM). The results of several measurements are effectuated as a function of different AMS values, without FEC/ACK or with FEC/ACK, respectively. Each device may support up to 1500 bytes of RF payload. In this case, the shape of the payload bitrate curve is shown depending upon the number of hops, AMS, and ACK/FEC, as illustrated in the figures that follow.

Figure 3 and Figure 4 show the results of TANC and TIPCN, respectively, in bytes per second, versus AMS with modulation type QAM.

According to the results shown in Figure 3 and Figure 4, it can be observed that the TANC increases considerably for the AMS values increase until 500 bytes, then rises slowly from 500 bytes to 1500 bytes. Additionally, one can see that the number of hops can also promote a significant increase in TANC.

The results illustrated in Figure 5 show the comparison between TIPNC and TANC without any correction.

We notice that the Total IP network capacity is high relative to the TANC, especially between 0 and 600bytes.

Figure 6 shows the effect of protocols (on network capacity), which can detect and recover the lost packets such as FEC.

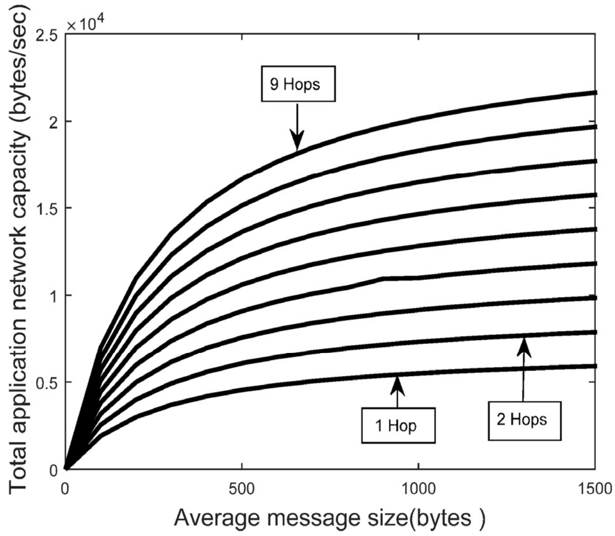

Figure 3. TANC vs. AMS: from n=1 hop to n=9 hops with identical retransmissions of Rayleigh channels using BPSK modulation Multi-Hop Path

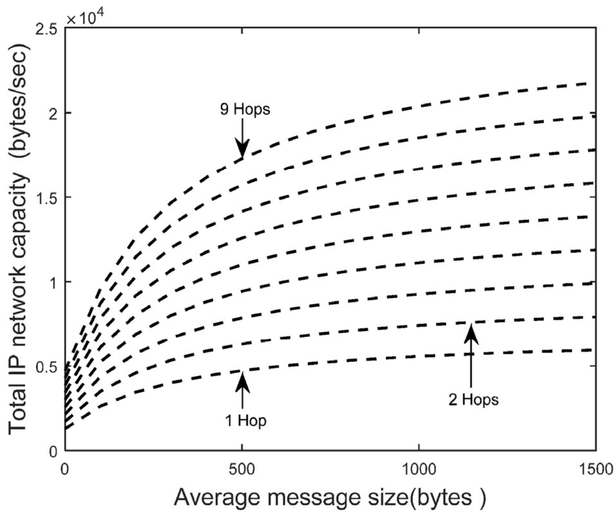

Figure 4. TIPNC vs. AMS: from n=1 hop to n=9 hops with identical retransmissions of Rayleigh channels using BPSK modulation Multi-Hop Path

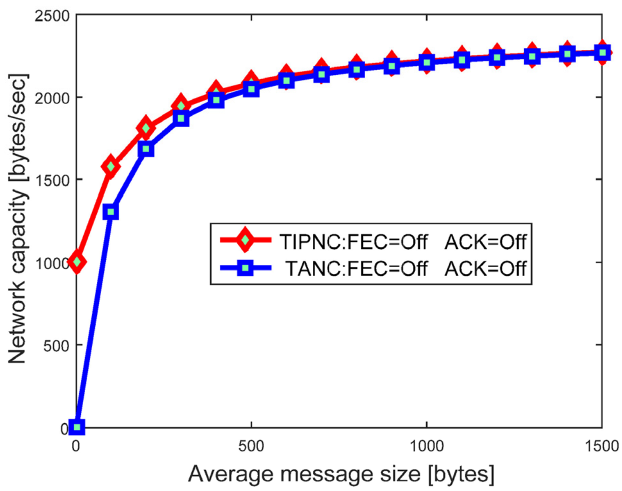

Figure 5. Total IP network capacity and Total application network capacity without any correction

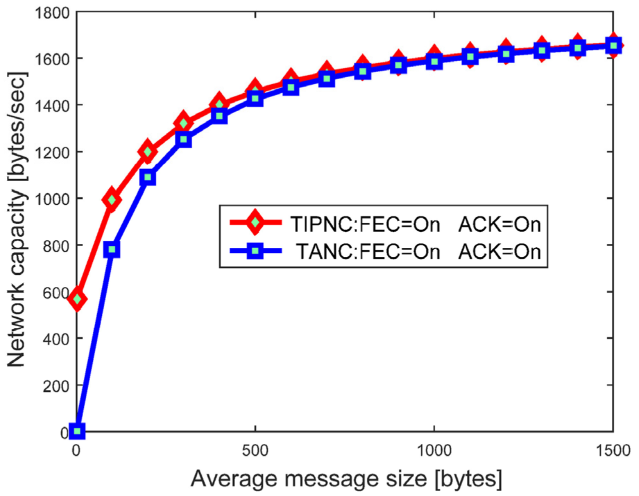

Figure 6. Total IP network capacity and Total application network capacity with correction

The results in Figure 6 show that the use of FEC, as well as ACK. in wireless networks, has a significant effect on the network capacity. Additionally, our results reveal that the techniques of packet loss recovery promote a further decrease in network capacity.

The scenario is considered in Figure 2: direct transmission between the successive neighbor devices using 9 routers. Figure 7 shows the comparison of Total IP network capacity results obtained for different configuration of FEC and ACK by considering different fixed message sizes

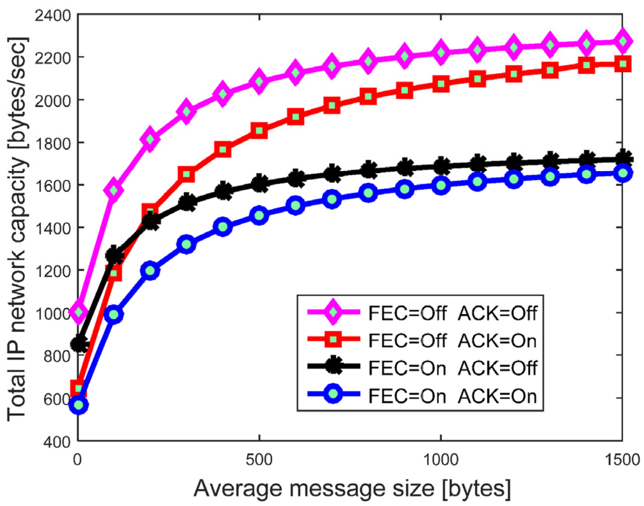

Figure 7. Total IP network capacity vs. AMS using a different configuration of FEC, and ACK

The results in Figure 7 show that the using different average message sizes (bytes) in wireless networks, without FEC/ACK or with FEC/ACK respectively, has a significant effect on the Total IP network capacity. Additionally, our results reveal that the FEC decreases the total IP network capacity channel more than ACK.

In the same way, Figure 8 shows the comparison of total application network capacity results obtained for different configurations of FEC and ACK.

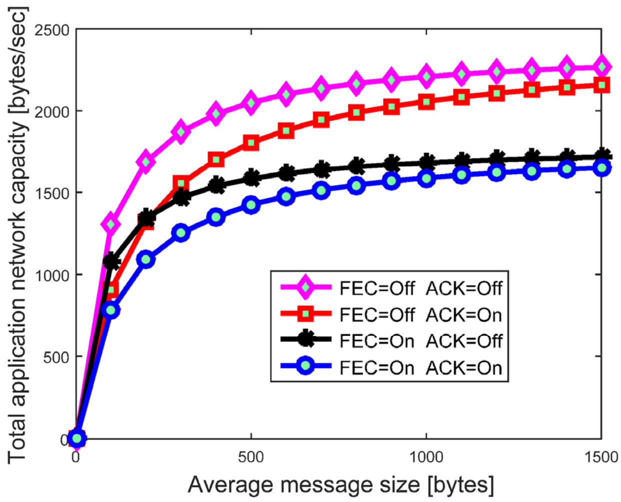

Figure 8. Total application network capacity vs. AMS using a different configuration of FEC and ACK

The introduction of ACK increases the TIPNC and TANC more than the presence of FEC.

Moreover, we can note that the results illustrate that the IP packet overhead promotes a further decrease in Total application network capacity. The use of FEC and ACK has the disadvantage of low network capacity.

To ensure the conformity of the experimental results, we compare them with the simulation result, as illustrated in Figure 9, which represents both practice and simulation curves. We take the case of ACK=on and FEC=on, and we have the following results.

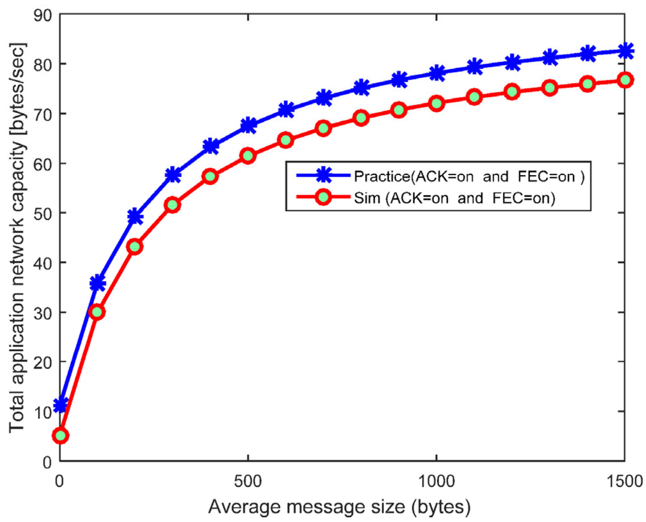

Figure 9. Comparison between the simulation and measurement results of Total application network capacity vs. AMS using FEC, and ACK

We find that the experimental and simulation results are almost the same.

To verify the effectiveness of the method with/without an error correction technique in transmitted data, the comparison results with (ACK) and without (FEC) are shown in the below Figure curves 10, Figure 11, Figure 12, and Figure 13.

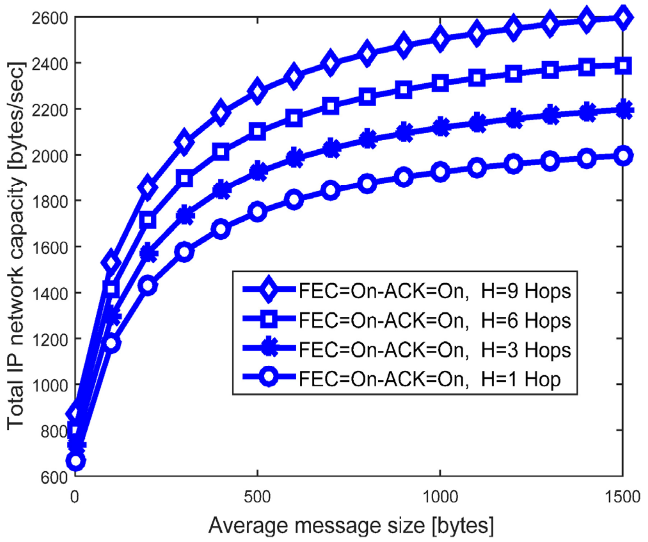

Figure 10. Total IP network capacity with FEC and ACK. for 1 Hop, 3 Hops, 6 Hops, and 9 Hops

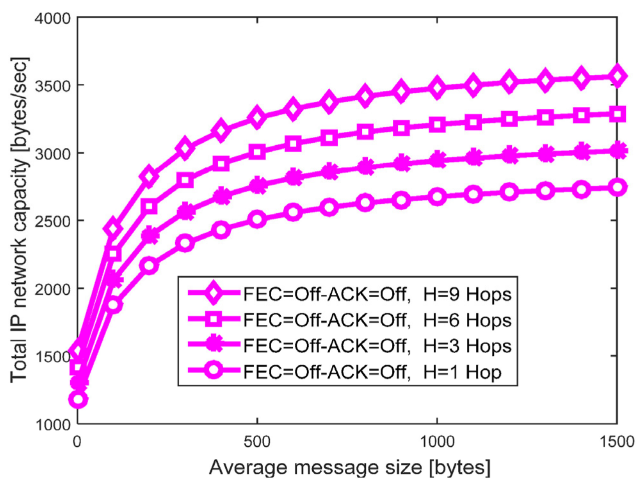

Figure 11. Total IP network capacity vs. AMS without any correction for 1 Hop, 3 Hops, 6 Hops, and 9 Hops

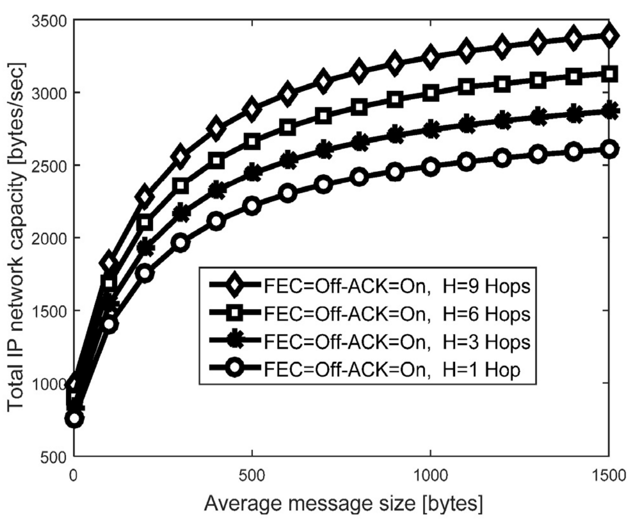

Figure 12. Total IP network capacity vs. AMS with ACK and without FEC 1 Hop, 3 Hops, 6 Hops, and 9 Hops

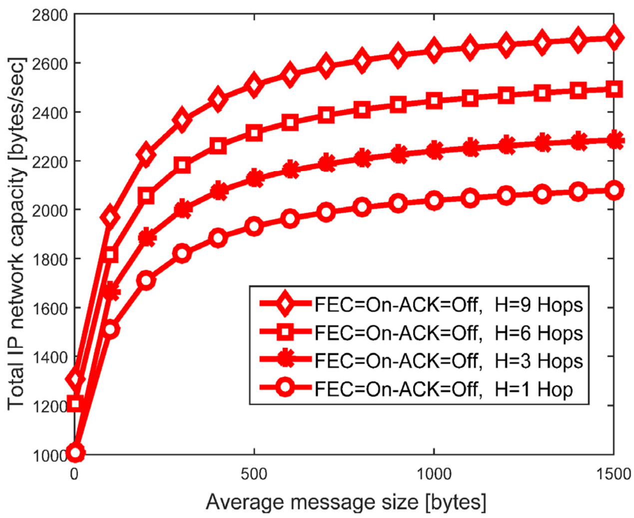

Figure 13. Total IP network capacity vs. AMS with FEC and without ACK for 1 Hop, 3 Hops, 6 Hops, and 9 Hops

The Figure 10, Figure 11, 12, Figure 13 show the comparison between measurement results of TIPNC versus AMS. for a combination of the four cases between the two famous error correction codes (ECC) using different hops. The comparison measurements show that the ECCs with hops have a remarkable improvement in network capacity versus message size.

The effect of the message size over network Total IP network capacity can be observed in graphical format in Figure 10, Figure 11, Figure 12, Figure 13. Initially, as the message size increases, the Total IP network capacity increases. Thus, the error corrector code and the number of hops have a significant impact on network performance. Also, we observe that the more the number of hops increases more the network capacity increase, tending the curves towards the horizontal.

Additionally, our results reveal that error correction techniques and multi-hop transmission affect varying network capacity compared to message size. The following Table 2 gives a summary of a comparative overview of a particular case of the result presented in Figure 13.

Table 2. Comparison of experimental values for FEC=3/4 - ACK =off

Message size [bytes]	Network capacity [bytes/sec]			
	FEC=3/4 - A.C.K. =off			
	Hops			
	1	3	6	9
0	1006	1007	1207	1308
500	1931	2124	2317	2510
1000	2037	2240	2444	2648
1500	2078	2285	2493	2701
Percentage	-	9.96%	9.10%	8.34%

Table 1 shows the comparison of experimental values for different hops with FEC=3/4 - ACK =off.

It has been observed that the number of hops increases with a slight decrease in the percentage of NC.

Figure 14 shows the variation of total IP network capacity depending on the average hops per path with AMS=1000 Bytes using a combination of different error-correction techniques.

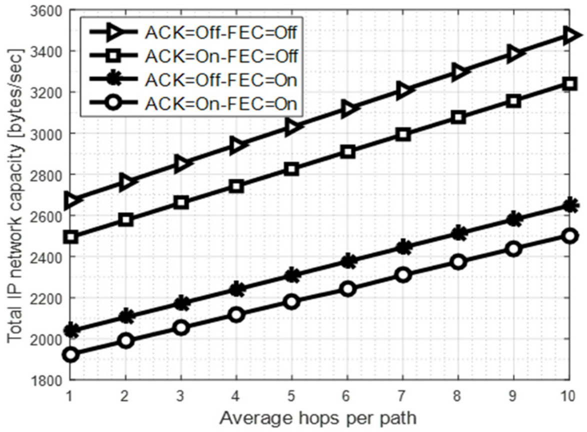

Figure 14. Total IP network capacity vs. Average Hops per path with AMS=1000 Bytes using a combination of different error-correction methods

Figure 14 shows that ECCs can reduce the total network capacity. The total IP network capacity using ACK represents an increase of 22.48% compared to the total IP network capacity using FEC.

We observe that the more hops per path, the less overlap, and consequently, more capacity left for simultaneous transmissions from different remotes. Nevertheless, this approach can be fully used only when there is a higher communication load.

6 Discussion

Computing and measuring the total network capacity can be a remarkably challenging and quite complex problem; the following Table 3 to explain the complexities.

Table 3 summarizes some classes of commonly encountered total network capacity complexities in measuring and calculating total NC that its measurement is our leading problem.

Table 3. Presentation of complexities during measurement operations of total network capacity

Name	Complexity	Examples of running Network capacity solution
Total Network capacity	Collisions	The total channel capacity is reduced to 25-35% because of the used protocol overhead needed to avoid and solve collisions.
	Error	Because we want to take accurate measurements to both minimize error and maximize capacity.
	calculate the data capacity	We have encountered a problem of an error that occurred while calculating the data capacity. This is based on the critical parameters selected by the proposed method.
	reduction in the network's capacity	Preferably error-correcting coding (FEC without retransmission /ACK with retransmission) can be handled separately, without a reduction in the network's capacity.
	Interference	Our proposed design is aimed to find an efficient method for computing and measuring the total network capacity minimizing the interference within the same IoT devices and among the nodes in the neighborhood. In this paper, the prospect of interference avoidance in IoT network was done using time division multiple access (TDMA) technology.
	Congestion	Avoiding congestion consists of maximizing the minimum remaining capacity of IoT devices in the network. The admitted flows in the network must not exceed the network capacity, To do so, The wireless channel must be kept from reaching the congestion point. This goal is hard to achieve since the channel is not only shared between IoT devices, that can communicate with each other directly, but extends to all IoT devices nodes within a specific range.

The existing wireless communication technologies due to the limitation of the network capacity. Several other works consider the capacity improvements [10] with the use of multiple channels and one or more radios [11] while the approach in [12] aims to increase the overall network performance by exploiting channel diversity and favor vertical traffic additionally.

From the analysis of the throughput in previous researches [7], it was defined as a function to find the value that achieves the maximum value of the network capacity. A managed mesh network is designed as the base network performing all communications for the network [13]. However, none considering the model with and without the two underlying error correction mechanisms ARQ and FEC as include in the proposed method.

Remote nodes offer unexampled data rates. The channel spacing available, the modulation type and rate, average message size, and signal levels expected/measured on individual hops limit the maximum data rate that can be exploited to provide redundancy of transmitted data. However, a lower data rate implies a longer transmission time for each packet length. This limits the maximum average message size; to ensure other end IoT nodes get time to use the network as well as real-time. WMNs, irrespective of its simplicity, face a significant limitation of limited network capacity. WMN capacity is minimal due to the limited bandwidth available and the use of a multihop wireless relay. One crucial direction,for improving the capacity of WMNs,is to use multiple radio interfaces and multiple channels simultaneously

The data rate defines the total capacity of one radio channel, which is shared by all the IoT nodes within the isolated area. Then several overhead factors, which diminish the total capacity, have to be considered. They are RF protocol headers, FEC, ACK, channel access procedures, and the number of store-and-forward IoT repeaters. Using ACK, FEC, average hops per path, and average message size for evaluating the total capacity can valuable the contributions of this work. Using the present method, the strengths from the methodological point of view of other different works become weak compared to the proposed method. This approach is new, and it can be inserted in the context of wireless, especially in a narrowband WMN of existing methods.

In several works, NC’s definition is reviewed to get a clear overview of how capacity should be estimated. These definitions are the base for selecting the functional and practical parameters to include in the system model. Our approach describes the measured network capacity giving a quick and easy idea of the possible capacity in the WMNs. The parameters on which this capacity is based are numerous, and each on his side quickly describes WMN performance. This approach is generally absent in the other methods.

Finally, to evaluate the performance of the proposed method, it was compared with other existing methods, and the distinction between parameters on which the network capacities are based was shown in Table 4.

As shown in Table 4, the network parameters regarding the proposed method indicate the service quality experienced by the subscriber giving a fast performance overview based on several basic parameters. They consist principally of the following:

- ACK.
- Channel spacing [kHz].
- Modulation type.
- FEC.
- Average message size

The proposed method outperformed some existing methods giving network performance with a more robust and detailed option. It achieves outstanding network capacity recognition performance for different parameters. In practice, the proposed method can show that the network capacity depends not only on the parameters mentioned above but also on the Channel spacing: 6.25 / 12.5 / 25 / 50 / 100 / 150 / 200 kHz and linear and exponential modulation.

Table 4. Comparison with other methods depending on some basic parameters that must be taken into consideration

Methods	Parameters
Ouni [4]	- Routing protocols. - Number and location of gateways bridging. The network to the Internet. - Physical network topology.
JANGEUN JUN [10]	- Network topology. - Number and position of the active nodes. - Bottleneck collision domain, which throttles the throughput
Köbel [12]	- Link-state routing information. - Channel Assignment. - Sublayer 3 traffic. The presented approach aims to increase the overall network performance by exploiting channel diversity. - Additionally, favor vertical traffic.
Ohnishi [13]	- Physical transmission rate. - Available spectrum - Queueing theory.
Cheng [7]	- Flow Constraint. - Carrier sense multiple access with collision avoidance (CSMA/CA) medium access control (MAC) protocols.
The proposed	- Average hops per path. - Interface speed. - Operating Mode. - Radio protocol. - ACK. - Channel spacing [kHz]. - Modulation type. - Modulation rate [kbps]. - FEC. - Collision domain. - Average message size.

The comparisons show that the methods perform using different rates of success in various settings.

7 Conclusions

In this paper, we focus on the analysis of TNC over a multi-hop, wireless network technology, designed for the IoT, where all links share the same physical channel. Our analysis shows that it is often difficult to improve both the TNC and the ECC simultaneously. Number hops and average message size adversely affect the TNC. We have analyzed how basic settings such as FEC and ACK affect the overall NC under different operating conditions. Also, we have exposed that the problems of error correction and capacity network can be separated without limiting the capacity of the network as a whole.

Furthermore, the analysis of the result shows that the Error-correcting codes, such as FEC and ARQ, have two opposite effects on the efficiency of TNC with different lengths. Although ECC dramatically increases the reliability and performance of the overall system, the ECC makes signals more robust, in contrast, reduce the total network spare capacity. It also shows that there is a direct relation between TNC characteristics, packet size, FEC, and ACK. It should also be noted that the increase in hops by path causes a reduction in the overlap. That is the reason for the higher capacity with more hops in the network. In the future, we would like to focus on fast-forwarding strategy at the intermediate nodes to improve the end-to-end delay using new performance algorithm as well as a news forwarding strategy to prolong the stable period of IoT devices by maintaining balanced energy consumption

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