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RESEARCH ARTICLE

Multichannel Slotted ALOHA Simulator Design for Massive Machine-Type Communication (mMTC) on 5G Network

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Abstract

Massive Machine-type Communication (mMTC) is one of the main service scenarios in 5G. At the time of initializing the connection to the base station, the MTC machines will make a connection request via the random access procedure. One of the schemes of random access procedure for handling this onnection request is similar to how multichannel slotted ALOHA works. Multichannel slotted ALOHA itself is a development of the slotted ALOHA scheme which originally has only a single channel. At the initial state of mMTC, there will be an explosion of the number of demands to the available channels. Given the number of machines that will be connected, the likelihood of a collision on the same channel increases. As a result, the probability of failure also increases. The system's configuration has an impact on the likelihood of success and the time it takes to achieve it. The number of channels influences the likelihood of collisions, the backoff window influences the transmission distribution in each slot, and the maximum transmission limits the ability of device retransmission. These three arrangements have an impact on one another. The simulator build in this research is expected to make it easier for researchers to optimize multichannel slotted ALOHA configurations in 5G to handle the surge in access demands from mMTC devices.

Keywords: Random access, 5G, network slicing, preamble, back off window

1. Introduction

Random access procedure is a procedure between devices and base station to initialize data transfer. Base station has shared resources. This means that in the mMTC scenario, devices can simultaneously perform random access procedures to be able to connect into the network. In order to achieve high connection density in mMTC, a random access scheme that can provide the best performance is needed [1]. ALOHA is a pioneer protocol in random access. ALOHA application is still quite relevant today. Slotted ALOHA can be used for satellite and LoRaWan uplink access, as well as an anti-collision protocol for RFID systems. One variation of ALOHA is Multichannel Slotted ALOHA. Multichannel Slotted ALOHA is an enhancement of Slotted ALOHA whose connection is divided into several timeslots. In this protocol, devices can transmit to a number of independent channels [2]. This system has been widely used to model random access channels in cellular networks [3]. The random access mechanism used in LTE and 5G cellular technology has quite a lot in common with multichannel slotted ALOHA. Simplifying the random access mechanism by analogizing it with multichannel slotted ALOHA can simplify the simulation and analysis of its performance. One of the procedures that needs to be optimized in order to meet the 5G latency objective is random access. However, research on the random access subsystem in 5G is still in its infancy. Due to the vast quantity of 3GPP documents that must be reviewed, novice researchers may have trouble researching this issue. Random access simulators are also difficult to come by. There are no official simulators from various vendors that provide independent simulations for random access.

This opensource Python-based random access simulator was made with the hope of narrowing the gap so that it could attract researchers into researching random access sub-systems.

2. Theoritical Basis

2.1 Internet of Things (IoT)

The term 'Internet of Things' was introduced by Kevin Ashton in his presentation about his work at MIT's Auto-ID Labs on networked radio-frequency identification infrastructure (RFID) [4]. In general, the IoT refers to objects that are connected to a network or internet so that they can exchange data with each other. ITU-T Y.2060 defines IoT as a global infrastructure that enables leading-edge services by connecting physical and virtual things based on interoperable information and communication technologies. By leveraging identification, data retrieval, processing and communication capabilities, IoT can maximize the utility of connected physical objects to provide services for various applications.

IoT performs the integration and interconnection of a large number of heterogeneous and complex systems. IoT architecture varies, depending on the characteristics of each. There is no consensus on an IoT architecture. However, there are three architectures that are the most dominant in their use. The architecture that is most often used is the architecture with three, four, and five layers. The most basic form is an architecture consisting of three main layers, namely physical devices, communications, and applications. Fig. 1 shows one of the architectures of the IoT [5].

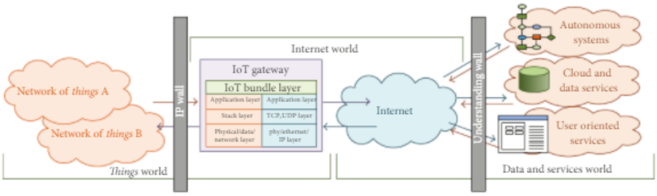

Figure 1. IoT Architecture

IoT, together with 5G, will support the realization of digital transformation, including Industry 4.0. Various industrial sectors will be affected by the existence of IoT which can exchange data and processes through the network. IoT is connected to the network by IoT communication protocol. Some of the most common IoT communication protocols are Bluetooth, Wi-Fi, cellular, and radio.

Mobile IoT communication can provide a large coverage area, but sometimes it does not reach certain areas. In addition, mobile IoT devices require more power. However, there are several new protocol developments in cellular for IoT such as Narrowband IoT (NB-IoT) which is gaining popularity as it can provide solutions to high power usage [6].

2.2 5G Cellular Network

Mobile networks have evolved for over more than three decades. The first generation of cellular or 1G networks, known as Advanced Mobile Phone System (AMPS), divides a geographic area into several cells with base stations to enable frequency reuse. 1G network communication mode is analog. Transformation from analog to digital takes place in GSM (Global System for Mobile)-based 2G cellular network which enables data with data rates of 9.6 Kbps. The 2G cellular network then evolved to 2.5G based on GPRS (General Packet Radio Service) and 2.7G based on EDGE (Enhanced Data Rates for GSM Evolution), both of which provide higher data rates of 160 Kbps and 500 Kbps.

In 1998, the popularity of internet increased and pushed forward 3G based on Universal Mobile Telecommunication System (UMTS). 3G has undergone many developments. Starting from Release 4 for efficient use of IP, HSDPA, and HSDPA+. The popularity of multimedia services has driven an evolution in telecommunications system architecture, along with the emergence of Long Term Evolution (LTE). The 4G cellular network improves 3G in term of mobile broadband services enhancement, also provides increased speed and bandwidth [7].

5G mobile network is a revolutionary technology. Fig. 2 shows the architecture of a 5G network. When compared to 4G, 5G provides lower latency, higher connection density, and higher peak data rate [9], as shown in Table 1.

The basic 5G technology consists of, Millimeter Waves, Small Cell Network, Massive MIMO, Beamforming, and Full Duplex. Millimeter wave (MmWave) provides additional spectrum. With a higher capacity, more users are supported and there can be more data. In addition, the additional spectrum also allows for a faster connection. It came with a cost. MmWave is not able to pass through obstructions or buildings, it

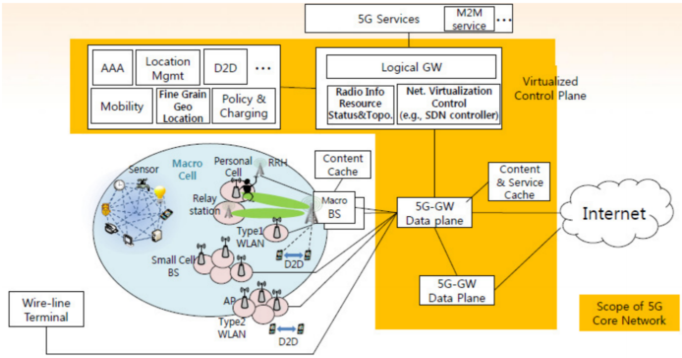

Figure 2. 5G Architecture [8]

Table 1. COMPARISON BETWEEN 4G AND 5G

Expectation	4G	5G
Latency	10ms	<1ms
Connection density	100.000 connection/km^2	1.000.000 connection/km^2
Peak data rate	1Gbps	20Gbps

also has a tendency to be absorbed by plants and rain. Therefore, a low-power mini base stations for switching called Small Cell Network was made to overcome this weakness. Massive MIMO uses a high number of antennas, making it more responsive for devices transmitting in high frequency bands, thus increasing the coverage area. However, the interference is high because of its tendency to broadcast in all directions at the same time. To overcome interference issue, Beamforming technology is used. Beamforming allows Massive MIMO base stations to direct radio signals to certain users and devices compared to all directions. On 5G network, transceivers can also send and receive data at the same time and frequency (Full Duplex) [10].

1G to 4G networks focused on human connectivity. But with more future technologies to be expected to come, 5G focus shifts from human interaction to machine or device interaction. Three basic use cases of 5G are shown in Fig. 3. These includes Enhanced Mobile Broadband (eMBB), Massive Machine-Type Communication (mMTC), and Ultra Reliable Low Latency Communication (URLLC). eMBB refers to high-speed mobile broadband networks, such as for Ultra HD video streaming. mMTC is a condition where a large number of devices are connected to the network, such as Smart City. URLLC offers reliable communication and low latency, enabling application such as self-driving cars and remote operation. 5G cellular network and IoT will drive a more advanced technology era, starting from Industry 4.0.

2.3 Massive Machine-Type Communication (mMTC)

Before entering the LTE era, communication was still focused on humans. Communication provides a way for humans to communicate with each other despite being

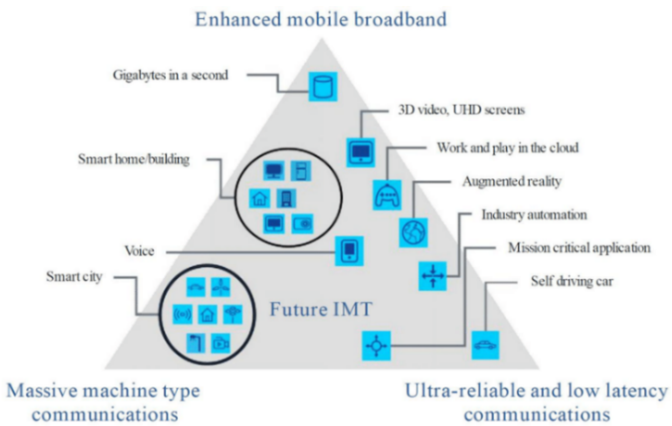

Figure 3. 5G Use Case Scenarios [11]

limited by distance. During its development, humans can call each other, exchange SMS, and make video calls.

4.5G and 5G cellular networks are no longer limited to Human-Type Communication (HTC), Machine-Type Communication will also be served. Machine-Type Communication is communication between machines or devices that form the basis of IoT. A simple example of machine-to-machine communication is smoke detection sensors in buildings connected to automatic sprinklers. When it detects a fire, the sensor will communicate with the sprinkler to pour water. This communication occurs without human involvement, so it can be called Machine-to-Machine (M2M).

With the technology promised by 5G, not only M2M will happen, but also Device-to-Device (D2D) which uses spectrum sharing without the involvement of base stations and Vehicle-to-Vehicle (V2V) in self-driving car applications. M2M, D2D, and V2V communications are also known as Machine-Type Communication (MTC) [12].

Massive Machine-Type Communication is a condition in which it is predicted that a large number of devices, at least ten times as many as today's mobile network users, with different quality-of-service (QoS) requirements, must be connected over the mobile network. MTC via cellular network has different requirements from HTC, including power limitations, deep sleep capability under certain conditions, large number of users, heterogeneous device types, varying delay requirements, and also special architectures.

In mMTC conditions, one of the challenges is the overhead signaling in the uplink by a large number of MTC devices trying almost simultaneously to connect to the network [13].

2.4 RAN Protocol Architecture

Radio Access Network (RAN) is a component that is directly related to user equipment (UE) to provide data or voice access to and from the UE. In the end-to-end carrier network architecture, RAN can connect with external networks through the core network [14]. RAN itself consists of radio base stations (BSs), base station controllers (BSCs), and backhaul networks.

Network Function Virtualization (NFV) turns traditional network hardware into virtual network functions. Along with Software Defined Networking (SDN), NFV is driving the evolution of traditional RAN to virtual. A traditional RAN with virtualized functions is called a Virtual RAN (vRAN). The development of RAN goes hand in hand with the development of 5G, so that the traditional network where the UE is associated with the cell is turned into a virtualized device centric network by Cloud RAN. The access point will be associated with the UE, as shown in Fig. 4. 5G network planning is contained in 3GPP Release 15.

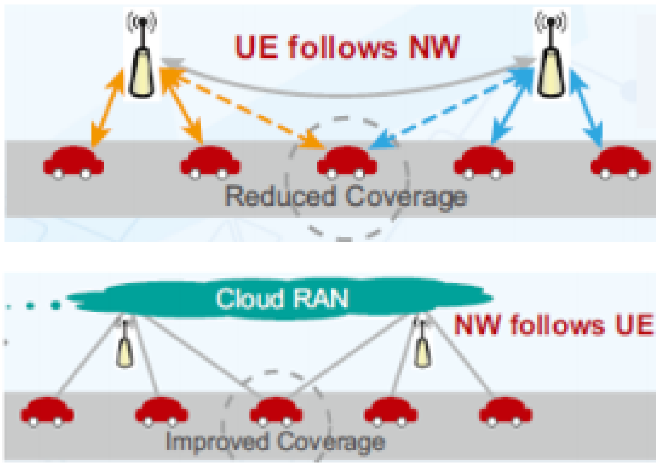

Figure 4. Traditional Network and Virtual Device Centric Network [8]

Base station on 5G is known as gNB. The gNB's internal architecture is separated into two parts, CU (Central Unit) and DU (Distributed Unit). The separation of this structure helps the process of virtualizing network functions. But basically, the components of the RAN protocol architecture did not change.

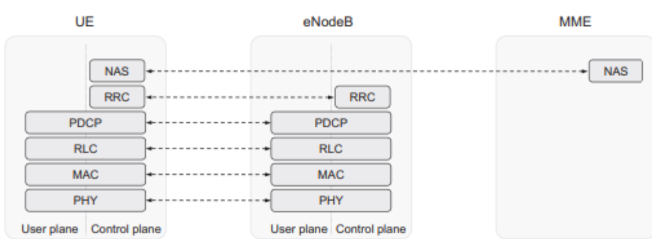

Figure 5. RAN Protocol Architecture in LTE [15]

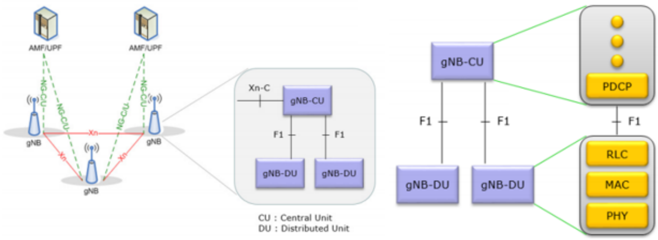

Figure 6. gNB Architecture [8]

Table 2. RAN PROTOCOL ENTITIES

Protocol	**Details**
Packet Data Convergence Protocol (PDCP)	Header IP compression to decrease the number of bits to transmit via radio interface
Radio Link Control (RLC)	Segmentation, handle retransmission, detect duplication, and in-sequence delivery for higher layer
Medium-Access Control (MAC)	Handle multiplexing from logical channels, retransmission of hybrid-ARQ, and scheduling for uplink and downlink
Physical Layer (PHY)	Handle coding/decoding, modulation/demodulation, mapping of multi-antenna, and other general use of physical layers [15]

2.5 Random Access Procedure

The random access procedure is a procedure where the UE makes a request to establish a connection with base station so that the it can use the network services. Simply put, this procedure is needed to initialize access between the UE and gNB [16]. This procedure was performed on Medium-Access Control (MAC) [17].

5G NR random access procedure is not much different from LTE. The main difference of the random access procedure between LTE and 5G NR is the dependency of RA preamble transmission with the reception of SSB in downlink, which is related to beamforming [18].

gNB transmits synchronization signals (PSS, SSS) and broadcast channels (PBCH) with beam sweeping in a routine basis. UE will then perform beam calculations to determine the best beam for synchronization. After that, UE performs MIB/SIB decoding on the beam. Remaining Minimum System Information (RMSI) and Other System Information (OSI) are carried by Physical Downlink Shared Channel (PDSCH).

The UE utilizes the same beam to execute random access by transmitting a RACH preamble randomly selected on the configured PRACH through Message 1. PRACH is a series of successive sub-carriers designed for preamble transmission, with the UE able to randomly choose from 64 orthogonal symbols. Upon reception of Message 1, the gNB replies with a Random Access Response (RAR) in Message 2. Message

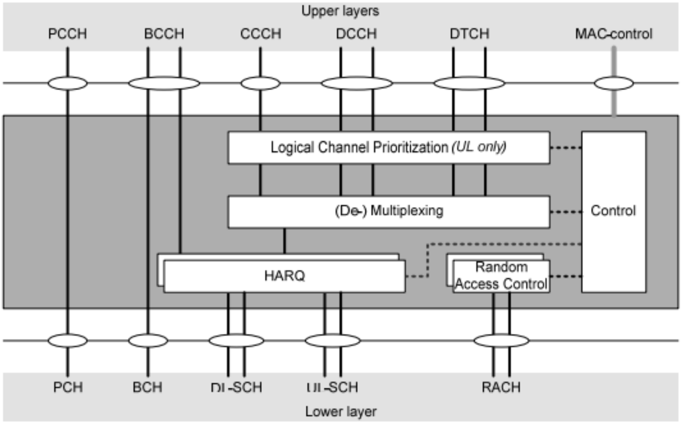

Figure 7. MAC Structure [15]

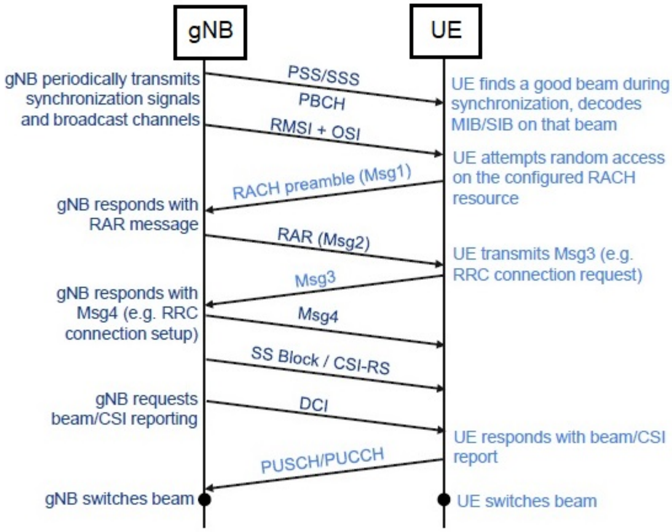

Figure 8. Random Access Procedure in 5G NR [19]

3 marks the initiation of the RRC connection request, where the UE dispatches an RRC Connection Request, met by the gNB's response via the RRC Connection Setup in Message 4. Collision issues during Msg3 arise when multiple devices opt for the same preamble, leading to a random back-off duration and retransmission with new preambles in PRACH. This cycle repeats until the maximum transmission is exhausted, resulting in an RA failure. In cases where no collision occurs, the UE obtains Msg4. The process follows the multichannel slotted ALOHA mechanism. The UE acquires SS and CSI-RS from the gNB for generating a beam/CSI report, responding to the gNB's beam/CSI report request with DCI through PUSCH/PUCCH. The random

access procedure concludes with a dedicated connection established between the UE and gNB using a specific connection ID [21]

2.6 Multichannel Slotted ALOHA

Multichannel slotted ALOHA is an extension of the slotted ALOHA protocol which refers to pure ALOHA. The flow of Pure ALOHA can be seen in Fig. 9 [20]. Flowchart in Fig. 9 shows a simple procedure of ALOHA with no time slots and single channel availability.

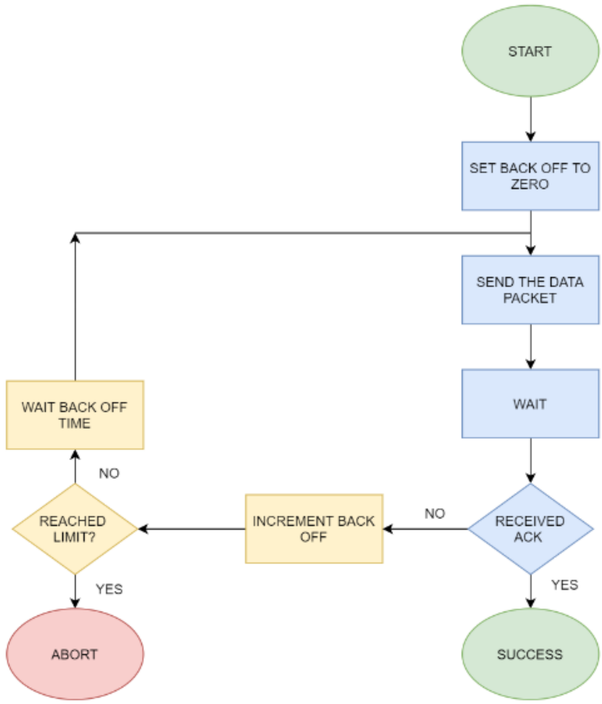

Figure 9. Pure ALOHA Flowchart [21]

In pure ALOHA, packets can be transmitted at any time by the connected device. This freedom of delivery time results in two possible collisions, namely partial collisions and complete collisions.

Fig. 10 shows an illustration of pure ALOHA and slotted ALOHA in a simulation for multi-tag identification [24]. Slotted ALOHA divides the available time into multiple timeslots so that packets can only be transmitted at the beginning of a certain timeslot. This mechanism eliminates the possibility of a partial collision because the packet will be transmitted at a certain time, leaving the IDLE timeslot and the complete collision. Vulnerable time of slotted ALOHA is half that of pure ALOHA, the maximum efficiency provided by slotted ALOHA is twice that of pure ALOHA.

In the random access procedure, slotted ALOHA is adopted in the presence of multichannel. This channel is called preamble in the random access procedure.

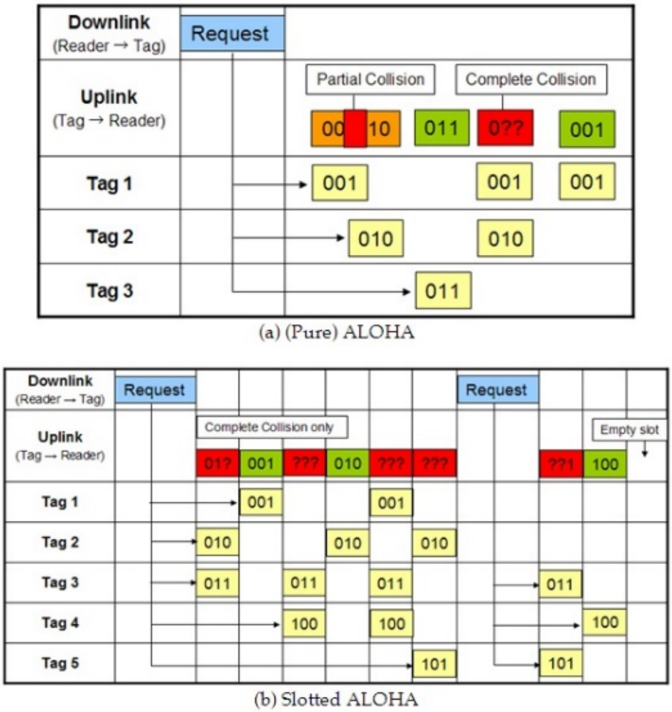

Figure 10. ALOHA Illustration [22]

Multichannel slotted ALOHA is a slotted ALOHA system where in each timeslot, the device selects a channel randomly.

ALOHA does not have the ability to detect collisions, in contrast to the random access protocols CSMA/CD and CSMA/CA which detect collisions first to prevent collisions. ALOHA allows collisions to occur, but provides a retransmission mechanism for devices experiencing collisions. Retransmission occurs when a device selects the same preamble/channel. There is a back off duration for devices to retransmit. The back off duration indicates the waiting range for the next timeslot to transmit.

3. System Planning

The design of the multichannel slotted ALOHA simulation is discussed in this chapter.

3.1 General Description

The simulation in this paper is intended to test the performance of multichannel slotted ALOHA as a simple model of the random access procedure that has been discussed in the previous chapter. The process of selecting a preamble (or channel, in the case of multichannel slotted ALOHA) which is done randomly creates the possibility of a collision. This happens because more than one device accesses the same resource.

One of the use case scenarios of 5G is massive Machine-Type Communication

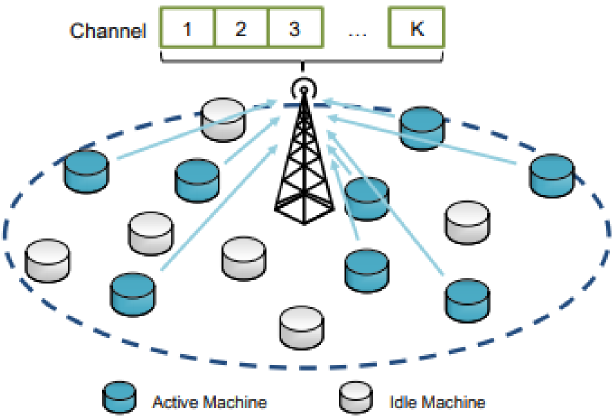

Figure 11. Multichannel Slotted ALOHA [23]

(MTC) as shown in the illustration Fig. 11, where 5G implements a target of one million devices per square km. This means, a large number of devices will access the same resource at the same time, resulting in congestion in RACH due to channel access requests from existing devices.

This simulation provides an idea of what effect can various parameters give to the success rate and delay when the devices try to initialize a connection to gNB. Fig. 12 shows an illustration of transmissions within the system.

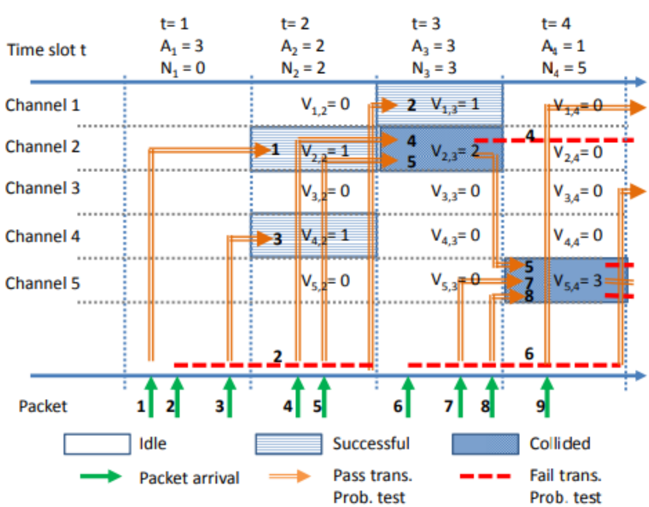

Figure 12. Transmission in Multichannel Slotted ALOHA [23]

In short, in multichannel slotted ALOHA, a device selects and transmits on a channel. Successful transmission occurs if no other device selects the same channel simultaneously; otherwise, retransmission is initiated. The device randomly determines a back-off duration during the first retransmission, incrementing the back-off window in subsequent attempts. This process continues within the back-off duration limit until the maximum allowed transmissions are reached, resulting in an unsuccessful overall transmission. For example, in a scenario with five devices aiming to connect to the gNB, each device sends a connection request with the chosen channel. The gNB allocates three channels for mMTC, each with a two-slot backoff indicator, allowing each device up to three transmission attempts.

Table 3. CONFIGURATION EXAMPLE

Configuration	**Value**
Channel Allocation	3
Backoff Window	2
Maximum Transmission	3

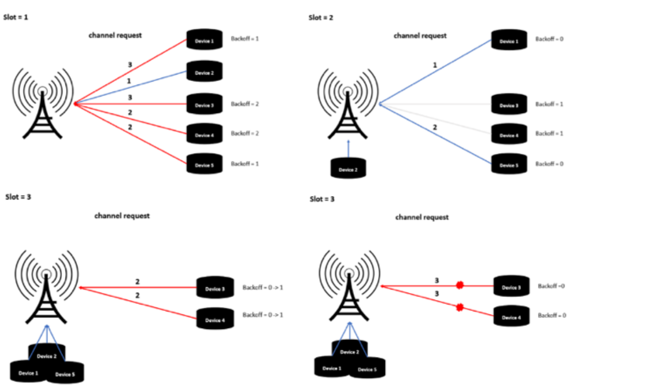

Figure 13. Simulation Illustration Each Slot

Fig. 13 depicts the outcome of a simulation involving five devices. In the first slot, all devices send requests on their chosen channels, with only the device selecting channel 1 avoiding collision. Collided devices initiate a backoff duration, and in this instance, devices 1 and 5 with a backoff duration of 1 slot can transmit in slot 2. Other devices await their backoff timer countdown to reach 0 for retransmission. Since devices transmitting at slot 2 choose different channels, they successfully connect to the gNB. In slot 3, remaining devices with a backoff timer of 0 send requests, resulting in a collision during the first retransmission. Both devices still have one retransmission opportunity, randomly updating the backoff duration to 1 and retransmitting in slot 4. Another collision occurs in slot 4, surpassing the maximum transmission limit, leading to RA failure.

There are four graphs generated in the multichannel slotted ALOHA simulator.

The X-axis and Y-axis of the graph are described in Table IV.

Table 4. OUTPUT GRAPH X-AXIS AND Y-AXIS

Graph	X-Axis	Y-Axis
A	Success probability	Number of devices
B	Delay	Number of devices
C	Transmission Distribution	Slot
D	Successful transmission distribution	Slot

Graphs A and B are performed on a certain range of devices, so they can see the probability of success and delay on a different total of devices. Graphs C and D are performed for a certain number of devices, intended to see the distribution of transmission and success rate in the timeslot range when all devices have done transmitting.

3.2 System Requirements

The simulator is made to be able to run the multichannel slotted ALOHA procedure in order to give results in accordance with Table IV. The basis for determining the design requirements of the system is to adjust the slotted ALOHA multichannel groove which is a modification of pure ALOHA with timeslot and more than one channel available. Some of the required system requirements can be formulated as follows:

1. The system can do random selection so that the device can choose the channel and back off.
2. The system can accommodate the implementation of procedures within the range of a certain total devices and a certain number of devices.
3. The system can log every process to observe every event that occurs and ensure that the simulation produces graphs that correspond to events.

The assumptions in the simulation:

1. During T slots, M devices always transmit packets in each slot as long as they have not reached the maximum transmission.
2. In each slot, there are R orthogonal channels so that they do not interfere with each other.

3.3 System

Multichannel Slotted ALOHA simulator uses Python programming language. This part discusses parameters and flow of the system.

After configuring parameters, devices transmit in the first slot, choosing channels. For failed transmissions, devices retransmit with a randomly selected backoff duration. The backoff decreases until zero, indicating transmission. Backoff range expands with collisions. The process concludes when all devices succeed or fail, with no further transmissions in the next slot.

Table 5. INPUT PAREMETERS

No.	Parameter	Details
1.	total_machine	Range of devices on simulation (1-total_machine)
2.	total_channel	Channel allocation
3.	backoff_window	Back off window
4.	max_transmission	Maximum number of transmission and retransmission
5.	range_check	Certain number within range to generate graph C and D
6.	repetition	Simulation repetition

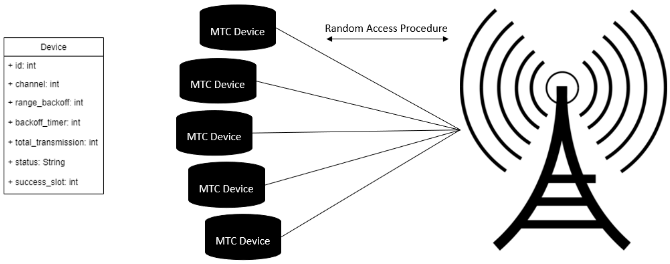

Figure 14. Simulation Illustration

Each device performs a random access procedure to connect to the network as shown in Fig. 14. Fig. 15 shows simulator flow chart.

'Device' in this simulator program is defined as an object of Device class. The Device class has attributes created with the needs of simulator in mind, so it includes but does not involve all elements in RACH Messages. The attributes and descriptions of the Device class are listed in Table 6.

3.4 Simulation Scenarios

Analysis is carried out based on the resource allocation and configuration of parameters below:

1. Channel
   - In 5G NR network, there are up to 64 orthogonal symbols for each PRACH which can be randomly selected by the transmitting device.
2. Backoff Window
   - When the random access procedure is not completed, a backoff time will be randomly selected between 0 and a value that refers to the Backoff Parameter Values. This value is set in 3GPP TS 38,321. One slot is assumed to be worth 10 ms. Thus, index 12 in Fig. 16 is worth 96 slots (960ms/10ms).

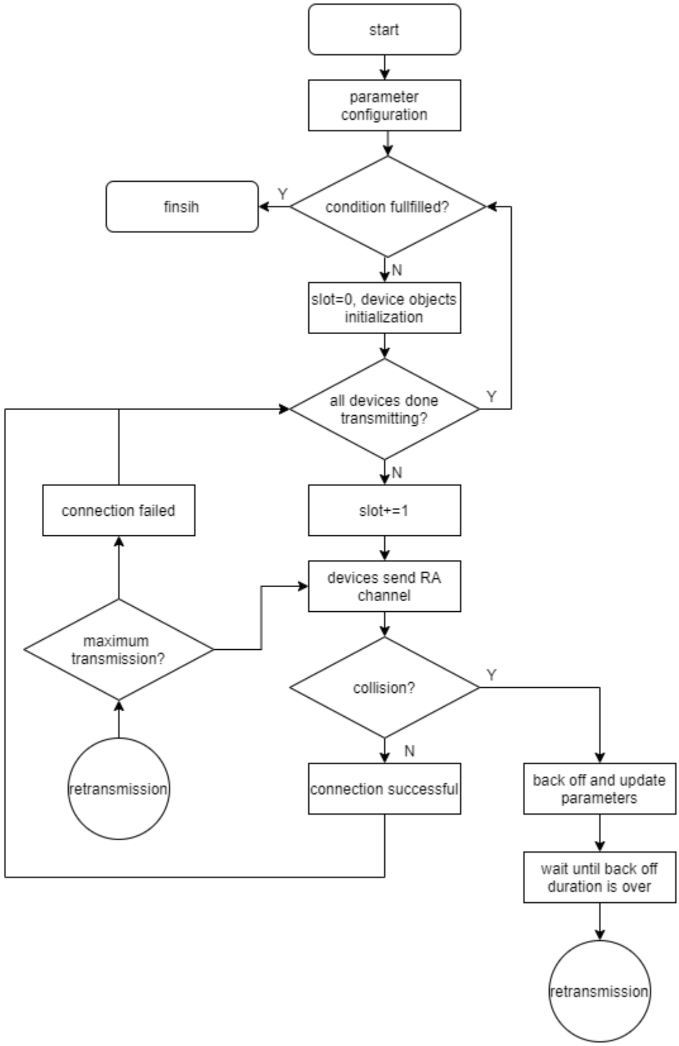

Figure 15. Simulation Flowchart

3. Maximum transmission
   - The maximum transmission value is the maximum number of transmission attempts the device can perform before declaring a failure. This parameter specification refers to 3GPP TS 36,331 in the RACH-ConfigCommon Information Element.

The main configurations of the simulation are listed in Table 7 and Table 8. Channel allocation, backoff window, and maximum transmission values in Table 7 are the smallest values of the parameter variations in Table 8 so that there is one condition that becomes a comparison to observe the impact of these three parameters.

Table 6. 'DEVICES' CLASS

No.	Attribute	Details
1.	id	Device ID
2.	channel	Chosen channel
3.	range_backoff	Chosen back off
4.	backoff_timer	*Back off countdown*
5.	total_transmissio	Total transmission done by device
6.	status	Status of device
7.	success_slot	Slot where the device succeeded

Index	Backoff Parameter value (ms)
0	0
1	10
2	20
3	30
4	40
5	60
6	80
7	120
8	160
9	240
10	320
11	480
12	960
13	Reserved
14	Reserved
15	Reserved

Figure 16. Back Off Parameter Values

```
PreambleTransMax ::=          ENUMERATED {
                                  n3, n4, n5, n6, n7,    n8, n10, n20, n50,
                                  n100, n200}
```

Figure 17. RACH-ConfigCommon IE

In this case, each graph will have one condition according to the values in Table 7, namely when the channel allocation is 16, the backoff window is 3 slots, and the maximum transmission is 3 times. The smallest value for the channel is chosen to anticipate the situation of low channel allocation, while the backoff window and maximum transmission values are chosen to limit delay.

Table 7. INPUT PARAMETER VALUES

No.	Parameter	Value
1.	Total device range	1000
2.	Channel	16
3.	Backoff Window	3
4.	Maximum Transmission	n3
5.	Total device (Graph C & D)	1000, 100
6.	repetition	50

Table 8. PARAMETER VALUES TEST

No.	Parameter	Value			
		1st	2nd	3rd	4th
1.	Channel	16	32	48	64
2.	Backoff window	3 (3 slot)	6 (8 slot)	9 (24 slot)	12 (96 slot)
3.	Maximum transmission	n3	n10	n20	n50

4. Analysis and Evaluation

The multichannel slotted ALOHA simulator result is discussed in this chapter.

Four types of simulations have been carried out with the following objectives:

1. A simple experiment, carried out with simple parameters that are not very realistic. This simple experiment aims to make it easier for readers to understand the procedures that occur in the simulation. This section describes the procedures that devices went through from the start of the program to the generation of resulting graphs.
2. Varied parameters to observe the effect of parameters on the probability of successful transmission and delay, is carried out by looking at the impact of different channel allocation, backoff window, and maximum transmission.
3. Varied parameters to observe the effect of parameters on the number of transmissions and the number of successful transmissions in each slot at high workloads, is carried out by looking at the impact of different channel allocation, backoff window, and maximum transmission.
4. Varied parameters to observe the effect of parameters on the number of transmissions and the number of successful transmissions in each slot at a certain load,

is carried out by looking at the impact of different channel allocation, backoff window, and maximum transmission. Certain load values are taken based on the results of the third type of simulation.

Each of the results shown below is the average result of the 50 simulations.

4.1 Simple Simulation Result

This section describes the simulation flow through the logs generated as one of the simulation program outputs. The log records the processes that occur in the simulation and their impact on the device attribute values in the Device class.

This simple simulation is carried out to prove that the simulation has run according to the targeted procedure. To summarize the explanation to make it easier to understand, the simulation in this experiment was carried out only for one particular configuration according to Table 9. The specific repetition value for this section is also shortened to two times.

Table 9. SIMPLE SIMULATION CONFIGURATION

No.	Parameter	Value
1.	Total device range	5
2.	Channel	3
3.	Backoff Window	2
4.	Maximum Transmission	2
5.	Total device (Graph C & D)	5
6.	repetition	2

This simple experiment involves 1 to 5 devices sending a connection request to gNB. The channel allocation that can be chosen randomly by the transmitting device is a total of 3 channels. Each device has a maximum transmission of 2 times. If the transmission is collided but has not reached the maximum transmission limit, that device will select a backoff duration randomly in accordance to the configured backoff window, which is 2 slots.

The results of this simulation are graphs of the success probability and delay for total devices 1 to 5, as well as graphs of transmission and successful transmission distribution at total device = 5.

Fig. 18 to 23 are resulting logs recording what happened in this simple experiment.

In Fig. 18, the log begins with a single device (ID=1) initialization. The device, yet to choose a channel, without a backoff value, successfully transmits on channel 1 in the first slot. In the second round, it selects channel 3 and achieves another successful transmission in slot 1. The average success probability for this device is 100% with no slot delay.

```
------------------------------------------
Repetition: 0
------------------------------------------
Initialization done.
ID=1,Channel=None,Back off Range=None,Back off timer=0,Transmission=0,Status=will_transmit,Slot=None
------------------------------------------
slot: 1
ID=1,Channel=1,Back off Range=None,Back off timer=0,Transmission=1,Status=success,Slot=1
------------------------------------------
------------------------------------------
Repetition: 1
------------------------------------------
Initialization done.
ID=1,Channel=None,Back off Range=None,Back off timer=0,Transmission=0,Status=will_transmit,Slot=None
------------------------------------------
slot: 1
ID=1,Channel=3,Back off Range=None,Back off timer=0,Transmission=1,Status=success,Slot=1
------------------------------------------
```

Figure 18. Resulting Log (1)

```
------------------------------------------
Repetition: 0
------------------------------------------
Initialization done.
ID=1,Channel=None,Back off Range=None,Back off timer=0,Transmission=0,Status=will_transmit,Slot=None
ID=2,Channel=None,Back off Range=None,Back off timer=0,Transmission=0,Status=will_transmit,Slot=None
------------------------------------------
slot: 1
ID=1,Channel=2,Back off Range=None,Back off timer=0,Transmission=1,Status=success,Slot=1
ID=2,Channel=1,Back off Range=None,Back off timer=0,Transmission=1,Status=success,Slot=1
------------------------------------------
------------------------------------------
Repetition: 1
------------------------------------------
Initialization done.
ID=1,Channel=None,Back off Range=None,Back off timer=0,Transmission=0,Status=will_transmit,Slot=None
ID=2,Channel=None,Back off Range=None,Back off timer=0,Transmission=0,Status=will_transmit,Slot=None
------------------------------------------
slot: 1
ID=1,Channel=3,Back off Range=None,Back off timer=0,Transmission=1,Status=success,Slot=1
ID=2,Channel=1,Back off Range=None,Back off timer=0,Transmission=1,Status=success,Slot=1
------------------------------------------
```

Figure 19. Resulting Log (2)

Fig. 19 is a log section representing an event when there are 2 devices. The simulator initializes two devices, namely device ID=1 and ID=2. In the first and second experiments for these 2 devices, the two devices chose different channels so there were no collisions. Both devices successfully transmit in the first slot. The average success probability for 2 devices is 100% with a delay of 0 slots.

In Fig. 20, three devices attempt to connect to the gNB, resulting in a collision in slot 1 of the first round when all devices choose channel 3. After setting a backoff duration of 2 slots, they retransmit in slot 3. Devices ID=1 and ID=2, selecting the same channel, fail due to exceeding the 2-time transmission limit. However, ID=3, opting for a different channel, succeeds.

In the second round, devices ID=1 and ID=2 collide again, but ID=3 succeeds. Both retransmitting devices choose a backoff duration of 2, preventing a collision in slot 3.

The first try has a probability of success of 33.33% while the second trial has a probability of success of 100%. On average, the probability of success for a total of 3 devices is 66.66%. Transmission for both rounds is completed in slot 3 so that the average delay is worth 2 slots.

Fig. 21 captures events with 4 devices, highlighting a unique occurrence where, unlike previous instances, two retransmitting devices opt for different backoff durations. In the initial attempt of the third slot, devices ID=3 and ID=4 both collide in slot 1. ID=3 selects a backoff duration of 1 slot, resulting in retransmission at slot 2, while ID=4, with a backoff duration of 2 slots, waits for the next slot. The chosen backoff

```
------------------------------------------
Repetition: 0
------------------------------------------
Initialization done.
ID=1,Channel=None,Back off Range=None,Back off timer=0,Transmission=0,Status=will_transmit,Slot=None
ID=2,Channel=None,Back off Range=None,Back off timer=0,Transmission=0,Status=will_transmit,Slot=None
ID=3,Channel=None,Back off Range=None,Back off timer=0,Transmission=0,Status=will_transmit,Slot=None
------------------------------------------
slot: 1
ID=1,Channel=3,Back off Range=None,Back off timer=0,Transmission=1,Status=collided,Slot=None
ID=2,Channel=3,Back off Range=None,Back off timer=0,Transmission=1,Status=collided,Slot=None
ID=3,Channel=3,Back off Range=None,Back off timer=0,Transmission=1,Status=collided,Slot=None
------------------------------------------
slot: 2
ID=1,Channel=3,Back off Range=2,Back off timer=1,Transmission=1,Status=wait,Slot=None
ID=2,Channel=3,Back off Range=2,Back off timer=1,Transmission=1,Status=wait,Slot=None
ID=3,Channel=3,Back off Range=2,Back off timer=1,Transmission=1,Status=wait,Slot=None
------------------------------------------
slot: 3
ID=1,Channel=1,Back off Range=2,Back off timer=0,Transmission=2,Status=failed,Slot=None
ID=2,Channel=1,Back off Range=2,Back off timer=0,Transmission=2,Status=failed,Slot=None
ID=3,Channel=3,Back off Range=2,Back off timer=0,Transmission=2,Status=success,Slot=3
------------------------------------------
------------------------------------------
Repetition: 1
------------------------------------------
Initialization done.
ID=1,Channel=None,Back off Range=None,Back off timer=0,Transmission=0,Status=will_transmit,Slot=None
ID=2,Channel=None,Back off Range=None,Back off timer=0,Transmission=0,Status=will_transmit,Slot=None
ID=3,Channel=None,Back off Range=None,Back off timer=0,Transmission=0,Status=will_transmit,Slot=None
------------------------------------------
slot: 1
ID=1,Channel=2,Back off Range=None,Back off timer=0,Transmission=1,Status=collided,Slot=None
ID=2,Channel=2,Back off Range=None,Back off timer=0,Transmission=1,Status=collided,Slot=None
ID=3,Channel=3,Back off Range=None,Back off timer=0,Transmission=1,Status=success,Slot=1
------------------------------------------
slot: 2
ID=1,Channel=2,Back off Range=2,Back off timer=1,Transmission=1,Status=wait,Slot=None
ID=2,Channel=2,Back off Range=2,Back off timer=1,Transmission=1,Status=wait,Slot=None
ID=3,Channel=3,Back off Range=None,Back off timer=0,Transmission=1,Status=success,Slot=1
------------------------------------------
slot: 3
ID=1,Channel=3,Back off Range=2,Back off timer=0,Transmission=2,Status=success,Slot=3
ID=2,Channel=1,Back off Range=2,Back off timer=0,Transmission=2,Status=success,Slot=3
ID=3,Channel=3,Back off Range=None,Back off timer=0,Transmission=1,Status=success,Slot=1
------------------------------------------
```

Figure 20. Resulting Log (3)

duration aligns with the configured window, allowing devices to select a duration between 1 to 2 slots.

The average success probability in both rounds is 75% and the delay is 1.5 slots.

Fig. 22 in the log depicts an event involving 5 devices. Initialization occurs before the first transmission for several devices. If a device successfully selects a channel in slot 1 without collision, it is deemed successful. In case of collision, devices with collisions select a backoff duration within the configured window and wait for the backoff timer countdown to retransmit. A device exceeding the maximum transmissions but not successfully selecting a collision-free channel is declared a transmission failure (RA failure).

Fig. 23 concludes the log, summarizing average success probability, delay, number of transmissions, and successful transmissions to generate graphs A, B, C, and D based on the system design. Fig. 24 displays simulation results derived from values presented in Fig. 23.

4.2 Parameter Influence to Success Probability and Delay

On the left of Fig. 25 is the success probability for channel variations. More channel allocation resulted to higher average success probability across the same number of devices. However, the probability of success depicted by the graph is still relatively low considering the optimal condition of 100% success rate. Other elements contributing to this low probability of success are the configuration of the backoff window and

```
-------------------------------------------
Repetition: 0
-------------------------------------------
Initialization done.
ID=1,Channel=None,Back off Range=None,Back off timer=0,Transmission=0,Status=will_transmit,Slot=None
ID=2,Channel=None,Back off Range=None,Back off timer=0,Transmission=0,Status=will_transmit,Slot=None
ID=3,Channel=None,Back off Range=None,Back off timer=0,Transmission=0,Status=will_transmit,Slot=None
ID=4,Channel=None,Back off Range=None,Back off timer=0,Transmission=0,Status=will_transmit,Slot=None
-------------------------------------------
slot: 1
ID=1,Channel=1,Back off Range=None,Back off timer=0,Transmission=1,Status=success,Slot=1
ID=2,Channel=2,Back off Range=None,Back off timer=0,Transmission=1,Status=success,Slot=1
ID=3,Channel=3,Back off Range=None,Back off timer=0,Transmission=1,Status=collided,Slot=None
ID=4,Channel=3,Back off Range=None,Back off timer=0,Transmission=1,Status=collided,Slot=None
-------------------------------------------
slot: 2
ID=1,Channel=1,Back off Range=None,Back off timer=0,Transmission=1,Status=success,Slot=1
ID=2,Channel=2,Back off Range=None,Back off timer=0,Transmission=1,Status=success,Slot=1
ID=3,Channel=2,Back off Range=1,Back off timer=0,Transmission=2,Status=success,Slot=2
ID=4,Channel=3,Back off Range=2,Back off timer=1,Transmission=1,Status=wait,Slot=None
-------------------------------------------
slot: 3
ID=1,Channel=1,Back off Range=None,Back off timer=0,Transmission=1,Status=success,Slot=1
ID=2,Channel=2,Back off Range=None,Back off timer=0,Transmission=1,Status=success,Slot=1
ID=3,Channel=2,Back off Range=1,Back off timer=0,Transmission=2,Status=success,Slot=2
ID=4,Channel=2,Back off Range=2,Back off timer=0,Transmission=2,Status=success,Slot=3
-------------------------------------------
-------------------------------------------
Repetition: 1
-------------------------------------------
Initialization done.
ID=1,Channel=None,Back off Range=None,Back off timer=0,Transmission=0,Status=will_transmit,Slot=None
ID=2,Channel=None,Back off Range=None,Back off timer=0,Transmission=0,Status=will_transmit,Slot=None
ID=3,Channel=None,Back off Range=None,Back off timer=0,Transmission=0,Status=will_transmit,Slot=None
ID=4,Channel=None,Back off Range=None,Back off timer=0,Transmission=0,Status=will_transmit,Slot=None
-------------------------------------------
slot: 1
ID=1,Channel=3,Back off Range=None,Back off timer=0,Transmission=1,Status=success,Slot=1
ID=2,Channel=1,Back off Range=None,Back off timer=0,Transmission=1,Status=collided,Slot=None
ID=3,Channel=1,Back off Range=None,Back off timer=0,Transmission=1,Status=collided,Slot=None
ID=4,Channel=1,Back off Range=None,Back off timer=0,Transmission=1,Status=collided,Slot=None
-------------------------------------------
slot: 2
ID=1,Channel=3,Back off Range=None,Back off timer=0,Transmission=1,Status=success,Slot=1
ID=2,Channel=2,Back off Range=1,Back off timer=0,Transmission=2,Status=failed,Slot=None
ID=3,Channel=2,Back off Range=1,Back off timer=0,Transmission=2,Status=failed,Slot=None
ID=4,Channel=3,Back off Range=1,Back off timer=0,Transmission=2,Status=success,Slot=2
-------------------------------------------
```

Figure 21. Resulting Log (4)

Table 10. PARAMETER CONFIGURATION

Parameter	**Value for Varied Parameters Simulation**		
	Channel	***Backoff Window***	***Maximum Transmission***
Channel	16, 32, 48, 64	16	16
Backoff Window	3	3, 8, 24, 96	3
Maximum Transmission	3	3	3, 10, 20, 50

maximum transmission, whereas both parameters took the smallest value from the variation of the parameter configuration.

Channel allocation also experienced a decreased average success probability as the number of devices wishing to connect increases. This happens because the number of channels is limited while the number of devices is increasing. As a result, more and more devices ended up choosing the same channel. This condition has an impact on the high number of collisions that occur.

On the other hand, increasing the number of channels decreases the delay time as shown on the right of Fig. 25.

```
--------------------------------------------
Repetition: 0
--------------------------------------------
Initialization done.
ID=1,Channel=None,Back off Range=None,Back off timer=0,Transmission=0,Status=will_transmit,Slot=None
ID=2,Channel=None,Back off Range=None,Back off timer=0,Transmission=0,Status=will_transmit,Slot=None
ID=3,Channel=None,Back off Range=None,Back off timer=0,Transmission=0,Status=will_transmit,Slot=None
ID=4,Channel=None,Back off Range=None,Back off timer=0,Transmission=0,Status=will_transmit,Slot=None
ID=5,Channel=None,Back off Range=None,Back off timer=0,Transmission=0,Status=will_transmit,Slot=None
--------------------------------------------
slot: 1
ID=1,Channel=2,Back off Range=None,Back off timer=0,Transmission=1,Status=success,Slot=1
ID=2,Channel=3,Back off Range=None,Back off timer=0,Transmission=1,Status=success,Slot=1
ID=3,Channel=1,Back off Range=None,Back off timer=0,Transmission=1,Status=collided,Slot=None
ID=4,Channel=1,Back off Range=None,Back off timer=0,Transmission=1,Status=collided,Slot=None
ID=5,Channel=1,Back off Range=None,Back off timer=0,Transmission=1,Status=collided,Slot=None
--------------------------------------------
slot: 2
ID=1,Channel=2,Back off Range=None,Back off timer=0,Transmission=1,Status=success,Slot=1
ID=2,Channel=3,Back off Range=None,Back off timer=0,Transmission=1,Status=success,Slot=1
ID=3,Channel=3,Back off Range=1,Back off timer=0,Transmission=2,Status=success,Slot=2
ID=4,Channel=1,Back off Range=2,Back off timer=1,Transmission=1,Status=wait,Slot=None
ID=5,Channel=1,Back off Range=2,Back off timer=1,Transmission=1,Status=wait,Slot=None
--------------------------------------------
slot: 3
ID=1,Channel=2,Back off Range=None,Back off timer=0,Transmission=1,Status=success,Slot=1
ID=2,Channel=3,Back off Range=None,Back off timer=0,Transmission=1,Status=success,Slot=1
ID=3,Channel=3,Back off Range=1,Back off timer=0,Transmission=2,Status=success,Slot=2
ID=4,Channel=3,Back off Range=2,Back off timer=0,Transmission=2,Status=failed,Slot=None
ID=5,Channel=3,Back off Range=2,Back off timer=0,Transmission=2,Status=failed,Slot=None
--------------------------------------------
--------------------------------------------
Repetition: 1
--------------------------------------------
Initialization done.
ID=1,Channel=None,Back off Range=None,Back off timer=0,Transmission=0,Status=will_transmit,Slot=None
ID=2,Channel=None,Back off Range=None,Back off timer=0,Transmission=0,Status=will_transmit,Slot=None
ID=3,Channel=None,Back off Range=None,Back off timer=0,Transmission=0,Status=will_transmit,Slot=None
ID=4,Channel=None,Back off Range=None,Back off timer=0,Transmission=0,Status=will_transmit,Slot=None
ID=5,Channel=None,Back off Range=None,Back off timer=0,Transmission=0,Status=will_transmit,Slot=None
--------------------------------------------
slot: 1
ID=1,Channel=1,Back off Range=None,Back off timer=0,Transmission=1,Status=success,Slot=1
ID=2,Channel=2,Back off Range=None,Back off timer=0,Transmission=1,Status=collided,Slot=None
ID=3,Channel=2,Back off Range=None,Back off timer=0,Transmission=1,Status=collided,Slot=None
ID=4,Channel=3,Back off Range=None,Back off timer=0,Transmission=1,Status=collided,Slot=None
ID=5,Channel=3,Back off Range=None,Back off timer=0,Transmission=1,Status=collided,Slot=None
--------------------------------------------
slot: 2
ID=1,Channel=1,Back off Range=None,Back off timer=0,Transmission=1,Status=success,Slot=1
ID=2,Channel=2,Back off Range=2,Back off timer=1,Transmission=1,Status=wait,Slot=None
ID=3,Channel=2,Back off Range=2,Back off timer=1,Transmission=1,Status=wait,Slot=None
ID=4,Channel=3,Back off Range=2,Back off timer=1,Transmission=1,Status=wait,Slot=None
ID=5,Channel=3,Back off Range=2,Back off timer=1,Transmission=1,Status=wait,Slot=None
--------------------------------------------
slot: 3
ID=1,Channel=1,Back off Range=None,Back off timer=0,Transmission=1,Status=success,Slot=1
ID=2,Channel=2,Back off Range=2,Back off timer=0,Transmission=2,Status=failed,Slot=None
ID=3,Channel=2,Back off Range=2,Back off timer=0,Transmission=2,Status=failed,Slot=None
ID=4,Channel=1,Back off Range=2,Back off timer=0,Transmission=2,Status=success,Slot=3
ID=5,Channel=2,Back off Range=2,Back off timer=0,Transmission=2,Status=failed,Slot=None
--------------------------------------------
```

Figure 22. Resulting Log (5)

```
--------------------------------------------
Total device: [1, 2, 3, 4, 5]
Average Success probability: [100.0, 100.0, 66.66666666666666, 75.0, 50.0]
Average delay: [0.0, 0.0, 2.0, 1.5, 2.0]
Slot: [1, 2, 3]
Average total transmission: [5.0, 0.5, 3.0]
Average successful transmission: [1.5, 0.5, 0.5]
```

Figure 23. Resulting Log (6)

On the left of Fig. 26 shows the significant effect of the backoff window value to the average success probability even though the number of channels allocated is the smallest number of channel configuration variations, which is quarter of the maximum number of available channels. The larger the value of the backoff window, the more varied the turn for retransmission of collided devices. As a result, the probability of a collision decreases as compared to when a given backoff window has a narrow range. The explanation on how backoff window affects the probability of success will be more visible in the discussion of transmission distribution.

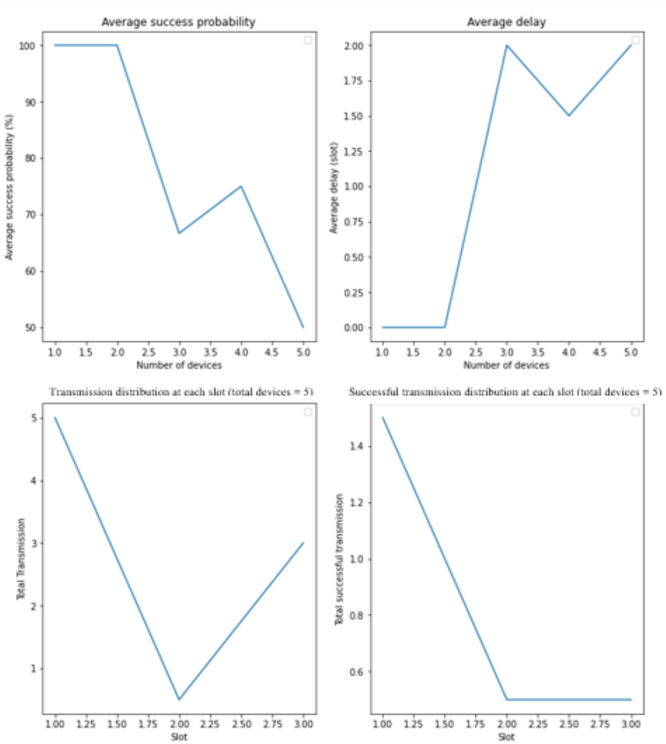

Figure 24. Resulting Graphs

However, although the addition of the backoff window value provides a higher probability of success, there is a tradeoff on the side of a higher delay as shown on the right of Fig. 26.

On the left of Fig. 27 shows that there exists a point where a drastic decrease happened after having 100% success rate for certain range of total device. This decrease is caused by the narrow backoff window in the configuration, which is 3 slots. Narrow backoff window causes the number of transmissions to be larger in a certain time interval and the minimal allocation of channels results in many collisions.

The graph shows that there is a point where even though the maximum transmission number is high, it can no longer accommodate the collisions that occurred. The number of collisions that are too many when the number of devices is increasing with a small channel allocation makes the number of devices that fail to transmit ended up higher, despite an increase in the maximum number of transmissions. Increasing the maximum number of transmissions also causes an increase in delay as a tradeoff, as can be seen in the graph in on the right of Fig. 27.

The obtained results reveal several key observations. Firstly, a higher number of channel allocations correlate with a decreased likelihood of collisions. Secondly, an expanded backoff window leads to more evenly distributed transmissions, subsequently reducing the probability of collisions. Thirdly, a greater maximum number

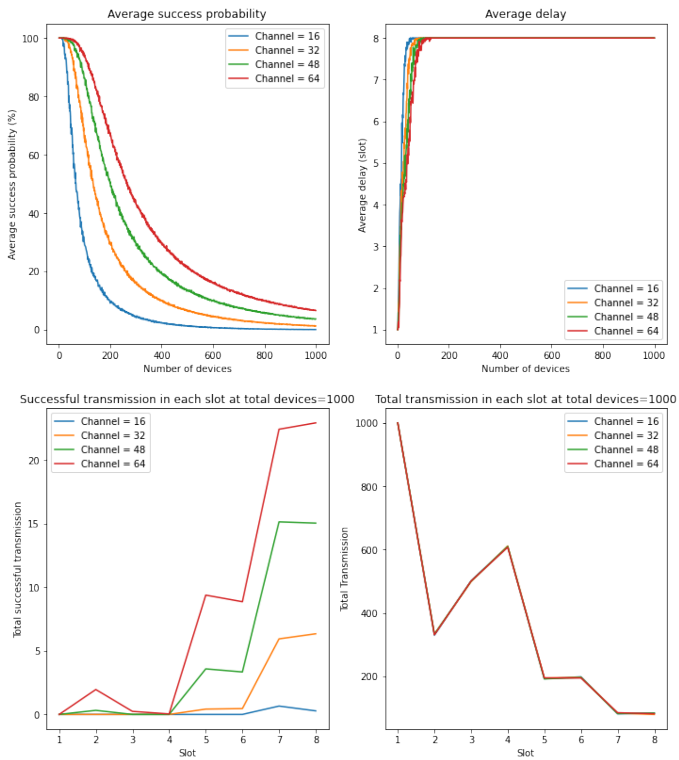

Figure 25. Average Success Probability (right) and Average delay (left) for Varied Channel Allocation

of transmissions increases the chances of retransmission, thereby enhancing the overall probability of success. However, it's noteworthy that elevated values for both backoff window and maximum transmissions, while offering improved success chances, come at the expense of increased delay, indicating a tradeoff between success probability and delay.

4.3 Parameter Influence on Transmission and Successful Transmission Distribution (High Load)

This section will demonstrate the state of the system at a high load using Table 10 configurations.

Variations in channel allocation affect the number of collisions that occur in each slot. However, the effect is not significant in the number of transmissions in each slot.

Initially, all devices transmitted the channel they chose. The number of transmissions that occurred subsequently decreases because devices chose different backoff durations. The relationship between the two graphs is inverse to one another. When there are many transmissions at a given point in time, only a small number of transmissions are successful. Whereas when there is a small number of transmissions at a given point in time, the greater the number of successful transmissions is. Channel

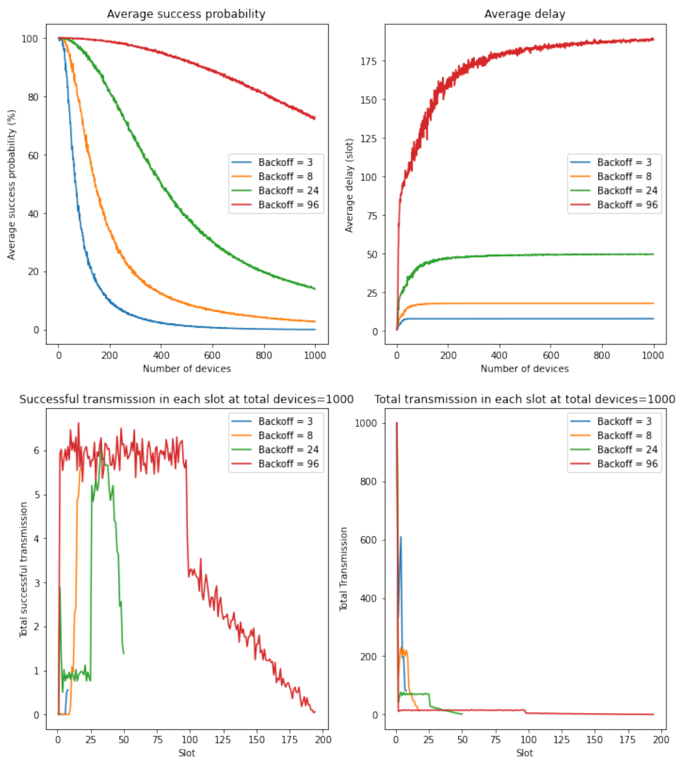

Figure 26. Average Success Probability (right) and Average delay (left) for Varied Backoff Window

Table 11. SUCCESS PROBABILITY RESULT

Parameter	Value	Success Probability
Channel	16	0.09 %
	32	1.32 %
	48	3.74 %
	64	6.58 %
Backoff Window	3	0.11 %
	8	2.79 %
	24	13.89 %
	96	72.92 %
Maximum Transmission	3	0.10%
	10	4.17%
	20	4.75%
	50	5.73%

variations caused an increase of successful transmissions due to a decrease in collisions

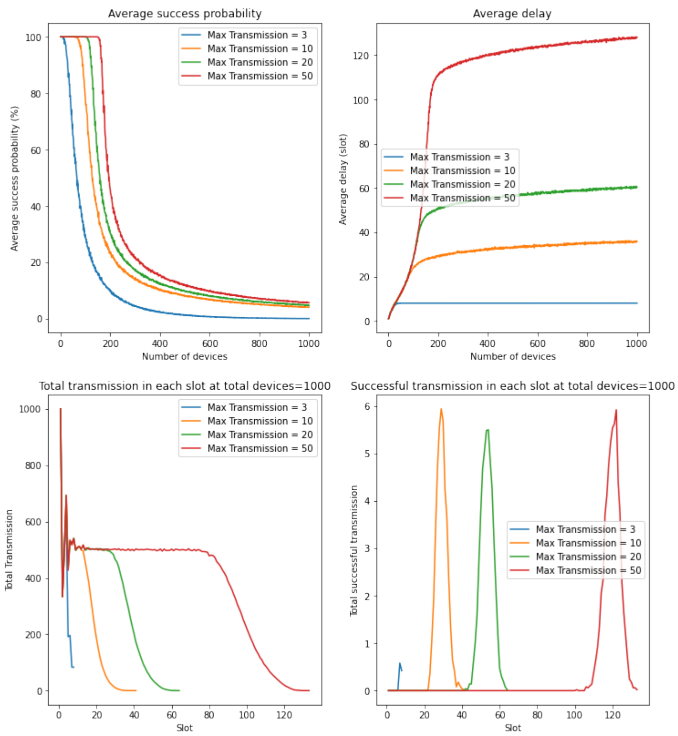

Figure 27. Average Success Probability (right) and Average delay (left) for Varied Backoff Window

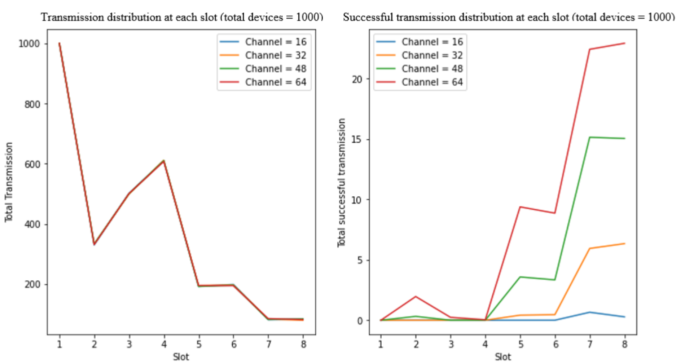

Figure 28. Transmission Distribution (left) and Successful Transmission Distribution (right) at High Load (Varied Channel Allocation)

when the channel allocation given is increasing.

Fig. 29 shows the transmission state in each slot for the backoff window variation. Transmission distribution is different from when channel allocation variations are carried out. This is caused by the value of the backoff window. The higher the backoff

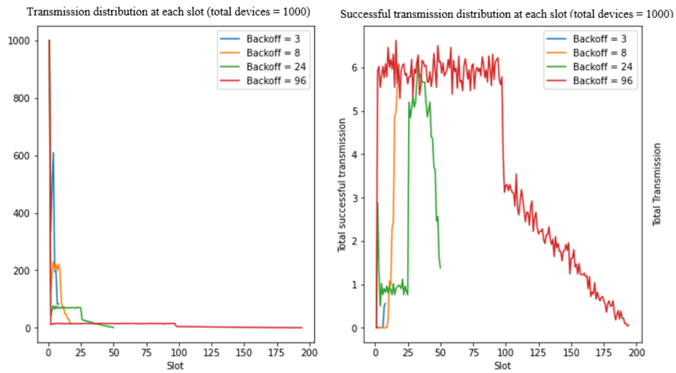

Figure 29. Transmission Distribution (left) and Successful Transmission Distribution (right) at High Load (Varied Backoff Window)

window value, the lower the number of transmissions that occur in each slot because the device has more options in the backoff durations to retransmit. As a result, the success rate is also higher when the probability of collision, supported by the spread of retransmission in more varied slot, decreases even though the number of channel allocations set is the minimum number in the experimental configuration.

However, at a certain point, there was a significant decrease in the number of transmissions and successful transmissions in the backoff window values of 24 slots and 96 slots in the graph. This condition occurs because some devices have reached the maximum number of transmissions, so that they are declared failed to transmit and are no longer transmitting, leaving a certain number of devices with a higher backoff range selection. a number of these devices still have a chance of transmission.

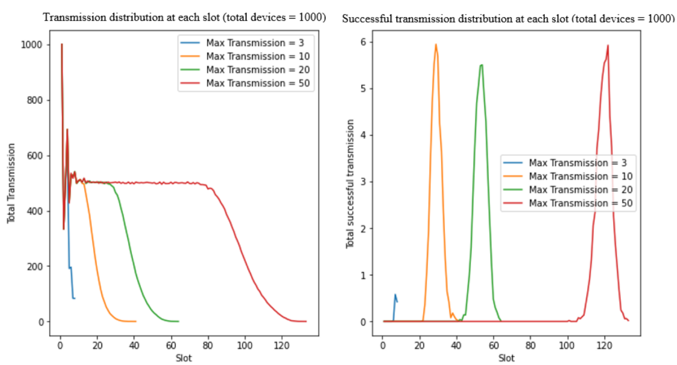

Figure 30. Transmission Distribution (left) and Successful Transmission Distribution (right) at High Load (Varied Maximum Transmission)

Fig. 30 shows a condition in which the possibility of a collision is high due to the narrow backoff window and the low channel allocation given. As a result, although the number of transmissions that occur is high thanks to the higher maximum number of transmissions, collisions caused large number of devices that want to connect to fail. At a certain point, the higher the device that does not transmit transmission again because it has been declared failed to transmit. This causes an increase in successful transmissions since the probability of collisions decreases. Along with the decrease in the number of transmissions, the number of successful transmissions also decreased.

4.4 Parameter Influence on Transmission and Successful Transmission Distribution (Total Device = 100)

This section used the same parameter configurations according to Table 10 with 100 devices. Total device = 100 was chosen to be able to demonstrate one of the conditions (refer to Part B) which had a 100% success probability but does not always produce a 100% success probability in other parameter variations.

Table 12. SUCCESS PROBABILITY RESULT

Parameter	Value	Success Probability
Channel	16	30.08%
	32	65.54%
	48	85.50%
	64	93.96%
Backoff Window	3	29.48%
	8	69.24%
	24	95.58%
	96	99.76%
Maximum Transmission	3	29.30%
	10	79.86%
	20	99.98 %
	50	100.00 %

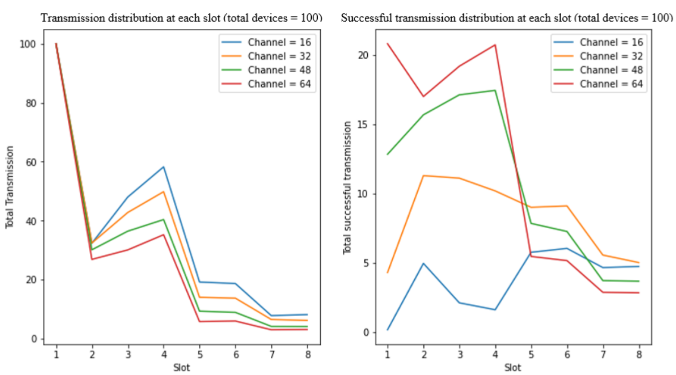

Figure 31. Transmission Distribution (left) and Successful Transmission Distribution (right) at Total Device = 100 (Varied Channel Allocation)

In Fig. 31, fewer channels lead to more transmissions, while more channels increase successful transmissions until slot 5 when channels 48 and 64 see a drastic decrease. Channel 64 has the lowest successful transmissions due to a surplus of successful devices, and the trend is similar for channel 48. Channels 16 and 32, with lower successful transmissions, require more retransmissions.

Fig. 32 shows that a larger backoff window results in a more distributed number of transmissions. A smaller backoff window yields more successful transmissions initially, but a larger window leads to fewer successful transmissions in each slot. Despite reducing collisions and enhancing success probability, a larger backoff window introduces a tradeoff in the form of increased delay, evident from the number of slots in the graph.

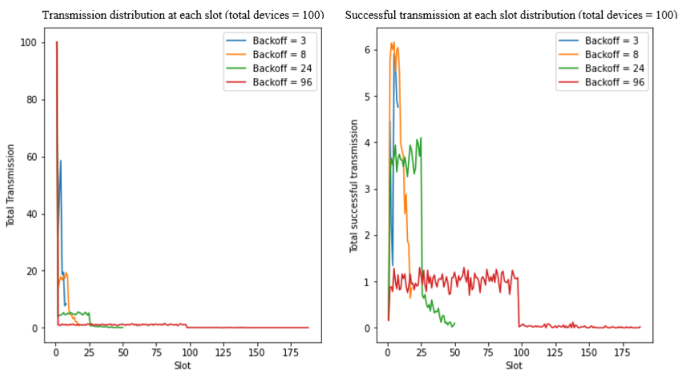

Figure 32. Transmission Distribution (left) and Successful Transmission Distribution (right) at Total Device = 100 (Varied Backoff Window)

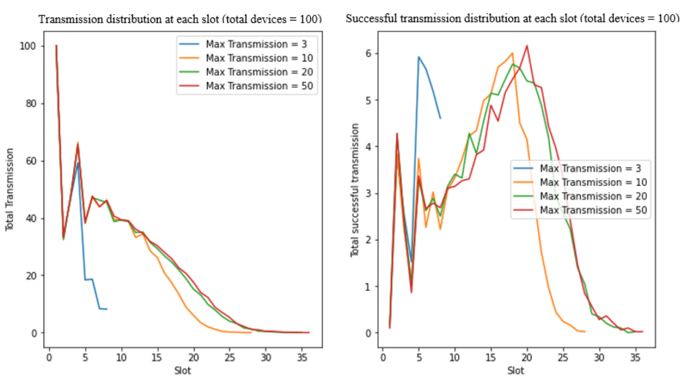

Figure 33. Transmission Distribution (left) and Successful Transmission Distribution (right) at Total Device = 100 (Varied Maximum Transmission)

Maximum transmission value, as seen on Fig. 33, affected the opportunity for the devices to retransmit. When the maximum number of transmissions is high, but all the devices have successfully sent the transmission, the maximum transmission is no longer significant.

For example, when all 100 devices successfully transmit with a 100% success probability at maximum transmission = 50, then giving a maximum transmission of 100 will not affect the number of successful transmissions or retransmissions. This event is represented by the number of transmissions of 20 and 50. The similarity of the number of transmissions and the number of successful transmissions both indicate that the maximum number of transmissions required to reach the full success rate is less than 50 and slightly more than 20.

5. Conclusion

Channel allocation influenced the number of collisions that occur in the network. The more channels are allocated, the smaller the collisions that occur. The backoff window affects the number of collisions and delays. When the backoff window range is larger, the distribution of the number of transmissions in each slot is increasingly varied, thereby reducing the number of possible collisions. However, the tradeoff of spreading the number of transmissions is higher delay. On the other hand, maximum transmission regulates the number of retransmission opportunities a device has when it encounters a collision. Increasing the maximum number of transmissions can increase the success of device connectivity.

Channel allocation, backoff window, and maximum transmission parameters impacted on each other. Therefore, proper configuration is needed so that the optimum success probability with lowest delay possible can be achieved. This simulation can be used to project the output of the configuration.

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