A Review on CSI and Equalization Mechanisms for Performance Enhancement in Slotted ALOHA Networks

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Abstract*— With the widespread growth of interconnected cyber physical systems, data transfer protocols which are simple to implement and have low computational complexity are useful. One such data transfer protocol is the ALOHA protocol which is particularly useful for the internet of things (IoT) and ultra narrow band (UNB) networks. One of the challenges which the ALOHA protocol experiences is the degradation in system throughput and increasing bit error rate (BER) for such networks due to ineffective bandwidth usage. This paper presents a detailed analysis of QoS metrics for IoT and UNB networks focusing on the ALOHA protocol. Additionally, a brief review on existing work in the domain is also cited. The QoS metrics have been presented so as to evaluate the performance of systems whose underpinnings is the ALOHA protocol.

***Index Terms*- Internet of Things (IoT), Ultra Narrow Band (UNB), ALOHA, Channel Sensing, Quality of Service (QoS).**

I. INTRODUCTION

The Internet of Things (IoT) has transformed the way gadgets connect, allowing for a wide range of applications, including smart homes and industrial automation. An essential element of the Internet of Things (IoT) is the communication infrastructure that links these devices [1]. Ultra-narrowband (UNB) networks have become a favorable choice among other possibilities because of their distinct advantages, such as high power efficiency, long-distance communication, and low data rates. Ultra-narrowband networks function by utilizing exceptionally narrow frequency bands, often ranging from a few Hertz to several kilohertz [2]. The limited range of frequencies available for transmission enables the spectrum to be utilized with great efficiency. This is especially beneficial in Internet of Things (IoT) applications, where devices frequently require the transmission of small data packets at irregular intervals. UNB networks are well-suited for environments with high signal congestion because they have a decreased bandwidth that helps minimize noise and interference [3].

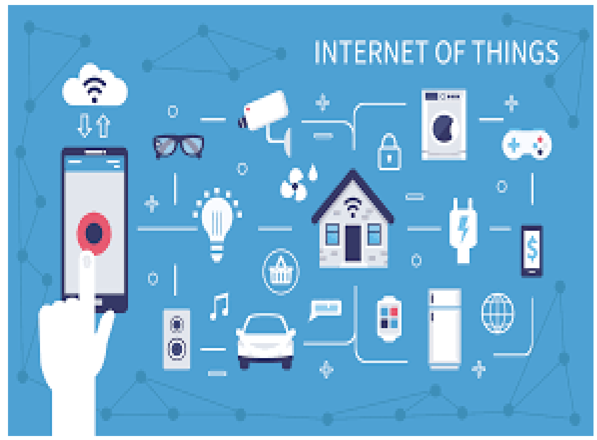

Fig.1 The concept of IoT
(Source: https://www.datamation.com/careers/iot-certifications/)

An important advantage of UNB networks in IoT applications is their increased range. UNB can achieve long-distance communication by focusing the signal power into a small band, making it crucial for IoT installations in rural and remote areas. In addition, UNB networks have a minimal power consumption, allowing IoT devices to function for extended periods of time using only one battery. This is essential for applications such as environmental monitoring or smart agriculture, where the frequent replacement of batteries is not feasible [4]. Ultra-narrowband IoT networks are highly suitable for applications that necessitate sporadic yet dependable data delivery. For instance, in the context of smart metering, utilities must get data from meters that are frequently situated in remote or inaccessible locations. UNB networks have the capability to transfer data over great distances without consuming a substantial amount of electricity. Similarly, in the context of asset tracking, UNB technology can offer dependable and accurate information regarding the whereabouts of commodities, all while minimizing the energy consumption of tracking devices [5].

As the IoT and UNB networks has a limited freelance bandwidth, hence it is necessary to utilize the bandwidth efficiently. The bandwidth efficient can be defined as:

$$\eta = \frac{Number\ of\ Transmission\ Channels}{Available\ Bandwidth} \quad (1)$$

Here,
η denotes bandwidth efficiency.

II. CSI AND EQUALIZATION IN SLOTTED ALOHA SYSTEMS

The ALOHA protocol is a fundamental media access control (MAC) protocol that enables devices to communicate data anytime they have data to send. Estimating the channel state information (CSI) and employing equalization for ALOHA systems allows for performance enhancement especially in error rate reduction. There are two primary variations: Pure ALOHA and Slotted ALOHA [6]. In the Pure ALOHA protocol, devices send data packets at any given moment, and in the event of a collision (when two devices transmit simultaneously), they wait for a random duration before attempting to broadcast again. Slotted ALOHA incorporates time slots, enabling devices to transmit exclusively at the start of these slots, hence decreasing the likelihood of collisions by 50%. The ALOHA protocol's simplicity is a significant advantage, as it may be easily implemented in IoT devices that have low processing resources. This simplicity is especially advantageous for IoT networks, as devices frequently possess limited processing capabilities and memory. Furthermore, the random access feature of ALOHA facilitates asynchronous communication, enabling IoT devices to promptly communicate data as soon as it becomes available. This is particularly advantageous for applications that necessitate real-time updates [7].

ALOHA is particularly suitable for a wide range of Internet of Things (IoT) applications, particularly those that require low data rates and intermittent transmissions. In environmental monitoring, sensors may be required to transmit data at irregular intervals depending on identified events, such as sudden increases in temperature or pollutant levels. ALOHA can effectively handle these messages without requiring intricate scheduling. In the field of smart agriculture, ALOHA can be employed by devices such as soil moisture sensors and weather stations to transfer data at regular intervals [7]. This ensures that updates are delivered promptly without putting excessive strain on the network. Various improvements have been suggested to overcome the constraints of the original ALOHA protocol. An example of an improvement is the implementation of Carrier Sense Multiple Access (CSMA), in which devices monitor the channel for activity before transferring data in order to prevent collisions. An alternative method involves employing hybrid protocols that integrate ALOHA with other MAC protocols in order to enhance performance. By integrating ALOHA with Time Division Multiple Access (TDMA), it is possible to achieve a harmonious blend of random access and scheduled transmissions, hence enhancing the efficiency of IoT networks [8].

There are several techniques for the sensing purpose of the cognitive channel which are being discussed here. Only the frontlines are being discussed here which show the maximum promise in the accurate spectrum sensing. This technique is used for the energy detection mechanism and senses the energy of the channel at any given point of time. The hypothesis that governs this technique is the following [9]:

$$h(t) = k(t);\ ideal\ no\ packet\ collision \quad (2)$$

$$h(t) = k(t) + j(t);\ collision\ present \quad (3)$$

The chances for a false alarm occur when there is collision present but the CSI suggest that collision is absent or vice versa. The chances of false alarm increase when there is actual addition of noise in the desired spectrum. It is noteworthy that such noise effects may lead to a false interpretation that there is collision noise being injected in the signal spectrum and it is the act of eavesdropping by the adversary. This however is not true and leads to misleading and inaccurate results. The effect can be summarized as follows [10]:

Let the threshold for collision to be present by 'T'

If $h(t) > T;\ Collision\ presnet$ (4)

However,

If $h(t) + n(t) > T$ holds true; (5)

Then there is a clear chance of false alarm often computed as the probability of false alarm of security threat.

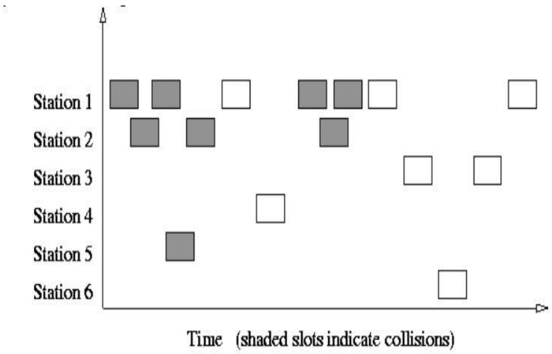

Fig.2 Transmission in Pure ALOHA

The transmission of channels in pure ALOHA is presented above.

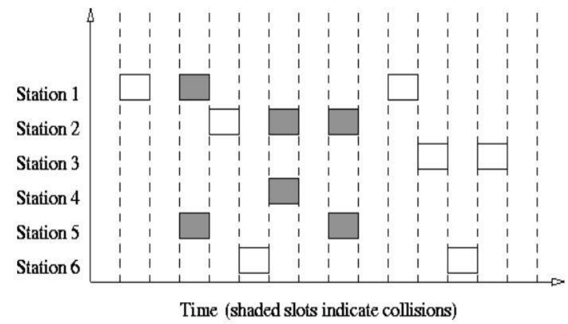

Fig.2 Transmission in Slotted ALOHA

The transmission of channels in pure Slotted ALOHA is presented above.
Slotted ALOHA was created as an improvement to Pure ALOHA in order to decrease the likelihood of collisions and promote network efficiency [11]. Slotted ALOHA is a communication protocol that divides time into distinct slots, allowing devices to broadcast data only at the start of these periods. When a device has data to send, it will delay transmission until the beginning of the subsequent time period. The implementation of this method decreases the likelihood of collisions as devices are coordinated to transmit data only at predetermined intervals. The main distinction between Pure and Slotted ALOHA resides in their collision probabilities and efficiency [12]. In the Pure ALOHA protocol, a collision may occur when two devices send data simultaneously, resulting in a significant likelihood of collisions. Theoretical maximum throughput of Pure ALOHA is approximately 18.4%. On the other hand, Slotted ALOHA effectively decreases the time period during which collisions can occur by permitting transmissions exclusively at the start of time slots. The synchronization results in a theoretical maximum throughput of around 36.8%, which effectively doubles the efficiency when compared to Pure ALOHA [13].

Another significant distinction between the two types lies in the intricacy of their execution. Pure ALOHA is easier to execute as it does not necessitate synchronization among devices. Each device has the capability to transmit data whenever it has information to send, which makes it well-suited for network settings that are less complex and have lower levels of traffic. Conversely, Slotted ALOHA necessitates a synchronization mechanism to synchronize devices with the time slots [14]. The increased intricacy can be rationalized by the enhanced efficacy and diminished collision rates in networks with greater traffic. The selection between Pure and Slotted ALOHA in IoT applications is contingent upon the precise demands of the network. Pure ALOHA is more suited for networks with low traffic and infrequent transmissions, such as remote environmental monitoring, where accidents occur less frequently. Slotted ALOHA is more suitable for dense IoT networks with regular data transmission requirements, such as smart city infrastructures, because to its improved efficiency [14].

The channel response of a typical wireless network is presented here:

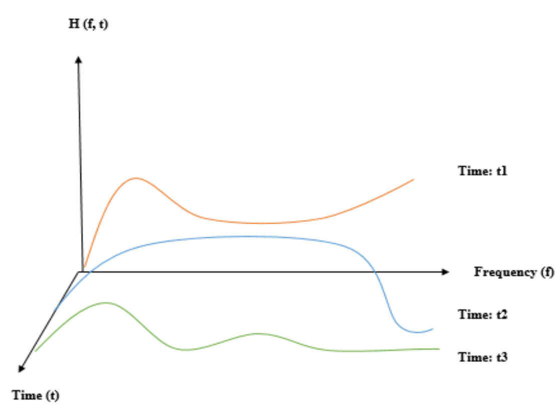

Fig.5 Channel Response

Wireless channels behave differently for different frequencies. The channel state information is the about the state of the channel. The state of the channel is generally a function of time. The practical wireless channels are generally functions of frequency and time both. Thus the channel behave slightly differently for different frequencies and the nature also varies differently for different times. Thus the channel gain also varies. The signals undergoing different fading effects generally will create different BER and Outage patterns at the output. The fading pattern depends on the attenuation constant [15].

The attenuation constant again depends on the material constants of the channel which are the permittivity, permeability, conductivity. It also depends on the frequency of transmission. Therefore the fading pattern would obviously vary with the frequency of transmission and also on the nature of the channel as it keeps changing with changes in the channel characteristics. Mathematically, the attenuation constant is given by [16]:

$$\alpha = \frac{\omega\pi}{2}\sqrt{\frac{1}{\sigma+\omega\epsilon}^{2} - 1} \quad (6)$$

Here,
α represents the attenuation constant
ω represents the angular frequency
μ represents the permeability of the medium
ε represents the permittivity of the medium
σ represents the conductivity of the medium

III. PREVIOUS WORK

This section presents a brief review on previous work in the domain.
Ramatryana et al. proposed a priority access (PA) that is based on non-orthogonal multiple access (NOMA) and uses slotted ALOHA (SA) for the large 6G Internet of Things (IoT) overload. At the physical layer, devices engaging in huge machine-type communication take advantage of the uncoordinated uplink NOMA, and at the medium access control layer, they use the SA protocol. Secondly, in order to maintain consistent throughput during an overload network state, PA is suggested to give priority to emergency devices over ordinary devices. Using traffic load estimation, each device determines how much traffic there will be on the IoT network and then uses an adaptive traffic load technique to determine how many packets to send. It is shown that the normalized throughput is improved by suitably applying priority access, and the PA controls the load of the IoT network above critical traffic load.

Silva et al. introduced a method to improve the data transfer rate in slotted ALOHA systems by leveraging the cognitive behavior of ALOHA systems. The cognitive radio network (CRN) approach improved the estimation of channel collisions by accurately calculating the channel state response. The authors analyze a Cognitive Radio Network (CRN) that utilizes the Slotted Aloha protocol. To enhance the system's performance, they suggest implementing an adaptive modulation mechanism. Determining the optimal transition moments between adjacent modulations is a crucial concern in the adaptive modulation system.

Gousaud et al. examined the concept of random un-slotted Time Frequency ALOHA. Its core and premise are in the Internet of Things. This concept is a recent and innovative approach to internet networking. It gathers data that can be employed in a wide range of applications for several purposes. The several facets can encompass industrial applications and residential automation, among others. The ALOHA protocol is being redesigned in accordance with the Internet of Things paradigm. This work aims to achieve successful generalization of ALOHA by applying it to frequency slotted systems such as the UNB. Time frequency random access is utilized. The integration of ALOHA with IoT can significantly enhance performance and yield substantial benefits.

Paolini et al. proposed the mechanism of coded slotted Aloha. This study also presented a random access technique that relied on error correction codes and eliminating interferences. Iterative interference subtraction is utilized to improve the functional metric value. This report presents a successful assessment of the ALOHA throughput using UNB data transfer.

Gallego et al. analyzed the performance evaluation of Frame Slotted ALOHA with consecutive Interference Cancellation in Machine to Machine Networks. The primary objective is to prioritize energy-efficient techniques, with a significant emphasis on the utilization of M2M machines to enhance energy efficiency. It acts as a gateway to many energy-efficient products and techniques. It has been demonstrated to significantly decrease both delays and energy consumption. Overall, it is a highly efficient and practical approach to guarantee excellent performance.

Stefanovi´c et al. presented an investigation of the Frameless ALOHA Protocol for Wireless Networks. The concept was derived from Slotted Aloha and is founded on the concepts of interference cancellation. The user data transfers are divided across multiple slots. They suggested a system that guarantees each user independent access to the wireless network with a predetermined probability. The primary objective of this action is to optimize the slot access mechanism, minimizing delays and issues, and ultimately improving the overall system performance. Additionally, it aims to ensure equal access for all users. The interference is rapidly eliminated, ensuring optimal performance and usefulness of the proposed system.

CONCLUSION

Based on previous discussions, it can be concluded that pure and slotted ALOHA are basic methods for regulating data transmission in UNB based IoT network systems. Pure ALOHA provides a straightforward and easily implementable solution, making it well-suited for networks with modest levels of traffic. On the other hand, Slotted ALOHA offers superior efficiency and decreased collision rates, rendering it more suitable for situations with larger levels of traffic. However, utilizing the channel response is crucial for utilizing the bandwidth effectively for ALOHA networks.

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