Performance Evaluation of LoRa and NB-IoT for IoT Applications

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Abstract— LPWAN is the most popular low cost, long battery lifetime, and long-range communication technology for IoT applications. This paper presents a comprehensive and comparative study on two leading LPWAN technologies called LoRa and NB-IoT. Regardless of the complexity of IoT schemes, all the systems rely on one common factor – an effective and reliable transportation mechanism for data and control information from/to the smart devices. The geometry of mines, especially the cross-sectional shape and the course, has a of major impact on the propagation behavior of the signal. Strong multipath nature of the wireless channel affects the smart wireless communication significantly in an underground mine environment. This paper considers this scenario of underground mines and explains which LPWAN technology fits best to guide future researchers and industrials. The paper explains how LPWAN systems provide reliable connectivity to the previously infeasible underground mining environment. A simulation study that compares the performances of LoRa and NB-IoT in mining area with strong multipath conditions is presented in this paper.

***Index Terms*—Wireless link performance, IoT, LPWAN, LoRa, NB-IoT, Multipath, Rayleigh fading, Underground Mines.**

I. Introduction

The Internet of Things (IoT) is an emerging paradigm in which everyday objects are equipped with Internet connectivity, enabling them to collect and exchange information. Currently, with the explosive growth of IoT technologies, an increasing number of applications can be found in the various fields such as security, asset tracking, smart industries, agriculture, smart metering, smart cities, and smart homes [1]. IoT applications have specific requirements such as low data rate, low energy consumption, long-range and cost effectiveness. Technologies such as ZigBee and Bluetooth have been widely adapted for short-range transmission, but they are not suitable in scenarios which require long-range transmission. Solutions based on cellular communications (e.g., 2G, 3G, and 4G) can provide larger coverage, but they drain the device's energy excessively. Therefore, the very specific requirements of IoT applications' have driven the emergence of a new wireless communication technology known as the low power wide area network (LPWAN).

With the increasing popularity of IoT devices, it is estimated that by 2025, around 30 billion IoT devices will be deployed around the world, a quarter of which will be connected to the Internet using Low-Power Wide Area Network (LPWAN) technologies [3]. LPWANs are emerging wireless technologies that complement traditional cellular and short-range wireless technologies to address diverse requirements of IoT applications. LPWAN technologies offer long-range connectivity for low power and low rate devices that are not provided by legacy technologies. LPWAN is increasingly gaining popularity in industrial and research communities because of its low power, long range, and low-cost communication characteristics. It provides long-range communication up to 10–40 km in rural zones and 1–5 km in urban zones. Besides, it is highly energy efficient (i.e. 10+ years of battery lifetime) and inexpensive, with the cost of a radio chipset being less than 2€ and an operating cost of 1€ per device per year [3]. Specifically, LPWAN technologies are considered for those applications that are delay tolerant, do not need high data rates, and typically require low power consumption.

It is essential for companies who deploy a large scale IoT system, to design a model for evaluating the performance of the system to avoid a setback in later stages. This paper would help in modelling the wireless communication system and to compare the performances between the two major technologies. The result presented in this paper would also be a significant part of a design process in sectors such as remote sensing, forestry, meteorology, smart cities etc., which uses Low Power Wide Area Network (LPWAN). The results could directly impact the industry sector who want to move towards Industry 4.0 or the IIoT (Industrial IoT) for improving their productivity or efficiency. Furthermore, Researchers who study LPWAN, IoT service providers, IoT product designers, government organizations (military, energy sector) and urban municipalities who want to integrate smart parking, smart waste management etc., find the results from the project useful in their design process.

In this paper, the performance of the two major LPWAN technologies LoRa and NB-IoT are presented and compared in terms of physical/communication features. To choose an appropriate LPWAN technology for an IoT application, various factors must be considered: range, coverage, device lifetime, latency, scalability, payload length, deployment, quality of service, and cost. This paper compares LoRa and NB-IoT briefly in terms of these IoT success factors based on results from previous research papers [1] [5]. The following section gives a brief overview of both technologies and their technical differences.

TABLE I

OVERVIEW OF LPWAN TECHNOLOGIES: LORA AND NB-IOT.[3]

	LoRa	NB-IoT
Modulation	CSS	QPSK
Frequency	Unlicensed ISM bands (868 MHz in Europe, 915 MHz in North America, and 433 MHz in Asia)	Licensed LTE frequency bands
Bandwidth	250 kHz and 125 kHz	200 kHz
Maximum data rate	50 kbps	200 kbps
Bidirectional	Yes / Half-duplex	Yes / Half-duplex
Maximum payload length	243 bytes	1600 bytes
Range	5 km (urban), 20 km (rural)	1 km (urban), 10 km (rural)
Interference immunity	Very high	Low
Authentication & encryption	Yes (AES 128b)	Yes (LTE encryption)
Adaptive data rate	Yes	No
Handover	End-devices do not join a single base station	End-devices join a single base station
Allow private network	Yes	No
Standardization	LoRa-Alliance	3GPP

A. *LoRa*

The word LoRa stands for long-range wireless communication system, is one of the LPWAN technologies developed by Semtech Corporation that is designed for M2M and IoT applications. In 2015, LoRa was standardized by LoRa-Alliance. It uses a patented spread spectrum technology using the unlicensed sub-GHz band (ISM band). The LoRa chirp spread spectrum (CSS) modulation technique takes advantage of the entire allocated bandwidth to transmit the signal, ensures full bidirectional communication, and the generated signal has low noise levels, enables high interference resilience [5]. Moreover, it enables long-range or wide coverage with efficient power consumption as well as low-cost communication system.

LoRa provides six spreading factors (SF7 to SF12) to adapt the data rate and range tradeoff. The highest spreading factor provides the longest transmission range and lowest data rate. The data rate is between 300 bps and 50 kbps and the maximum payload length for each message is 243 bytes.

B. *Narrow Band – IoT (NB-IoT)*

NB-IoT is an LPWAN technology based on narrow band radio technology and is standardized by the 3rd generation partnership project (3GPP). Its specifications were published in Release 13 of the 3GPP on June 2016 [3]. NB-IoT can coexist with GSM (global system for mobile communications) and LTE (long-term evolution) under licensed frequency bands. The frequency bandwidth of NB-IoT is 200 kHz, which is similar to one resource block in GSM and LTE transmission. The NB-IoT communication protocol is based on the LTE protocol. In fact, NB-IoT reduces LTE protocol functionalities to the minimum and enhances them as required for IoT applications. NB-IoT can be implemented with only a software upgrade to the existing LTE infrastructure and it is optimized for the features required for IoT. Hence, the end devices require only a small amount of battery, thus making it cost-efficient. The modulation technique used is Orthogonal Frequency Division Multiplexing (OFDM) and this ensures users obtain a high-performance level along with cellular connections. One potential problem is the network and tower handoff, hence NB-IoT is best suited for devices with fixed locations.

C. *Comparison in terms of IoT factors*

This section highlights the emerging LPWAN technologies and the technical aspects of LoRa and NB-IoT as summarized in Table 1. LoRa has an advantage in terms of power consumption/battery life because of the asynchronous, whereas in NB-IoT, due to infrequent but regular synchronization, the device consumes additional battery energy. Further, OFDM or FDMA require more peak current for the linear transmitter of NB-IoT. The major utilization advantage of LoRa is that it has a wider network coverage than NB-IoT network. Nearly a whole city could be covered by one gateway or base station. On the other hand, NB-IoT focuses mainly upon MTC class of devices that are installed at places far from usual reach.

NB-IoT can be deployed by reusing and upgrading the existing cellular network but its deployments are restricted to the area supported by a cellular network. On the other hand, the LoRa components and the LoRaWAN ecosystem are mature and production-ready now. LoRa uses unlicensed spectra whereas NB-IoT employs a licensed spectrum which is optimal for Quality of Service (QoS) at the expense of cost. Licensed LTE spectrum auctions are over 500 million euro per MHz [7]. The trade-off between QoS and high spectrum cost must be considered while choosing between LoRa and NB-IoT. It general LoRa has a huge advantage over NB-IoT in terms of cost. In summary, as shown in the Fig.1 one technology cannot equally serve all IoT requirements. The IoT factors and requirements will determine the feasibility of LoRa and NB-IoT for specific applications.

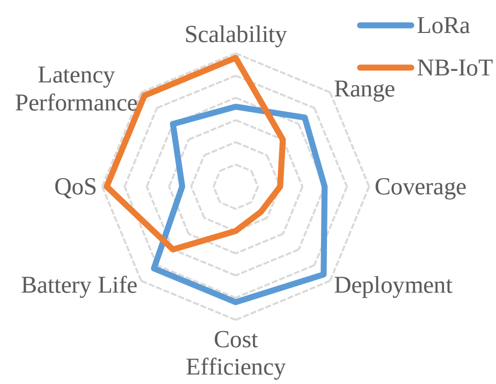

Fig. 1. Respective advantages of LoRa and NB-IoT in terms of IoT factors [5]

This paper shows how strong multipath environment can affect the performance of underground mines, describes the channel model and surveys which technology fits best in terms of the bit error rate against different signal to noise ratios (SNR) using the simulation results. The remainder of this paper is organized as follows: Section II explains the IoT application in underground mines. In Section III, the simulation setup is described, and section IV provides results with illustrations.

II. IoT in Underground Mines

In recent years IoT has been embraced by many industry areas such as logistics, manufacturing, retailing and pharmaceutical, and introduced a new subset of IoT called industrial IoT (IIoT). IIoT or smart industry is fully integrated and collaborative systems that target to monitor the environment to ensure the safe conditions, monitor the machines, track the inventory for more efficient supply chain management, utilize localization of both assets and worker, and finally enhance the production [8]. Advancement in sensor technology, data analytics and cloud technologies are the major driving force of IIoT. IIoT applications help in predictive maintenance and to optimize business processes with the help of smart devices which monitor the industrial environment and transmit the data to the controller using the communications infrastructure.

Among the infinite range of possibilities that IIoT is able to offer, one of the most useful is the implementation of smart mining industry. Most underground mining equipments was operated by humans in the past. Due to the safety-critical nature of this industry, there is a shift towards the equipment which is operated by smart IoT systems. These smart systems collect information from field sensors and interact using different communication technologies. These systems make intelligent decisions to manage the equipment and personnel which increases productivity, reliability, safety and reduce costs and human error [8]. However, smart system implementation challenges continue to persist in many industrial areas.

In mining IIoT, according to the applications need, end devices generate both regular and irregular types of traffics at different intervals. The systems regularly monitor physical environment parameters such as temperature, air flow, dust, seismic vibration, humidity, O2 level. The application also needs safety-critical measurements such as explosive particle levels of the mining environment to ensure safe conditions. The systems need to monitor the production conditions, as well as they, detect different events and alarms to ensure safety at the workplace. Therefore, different types of traffics are generated in an industrial application those have different Quality of Service (QoS) requirements such as deterministic latency, low energy consumption, reliability, and secure data transmissions to the application servers [9]. Therefore, a careful selection of the most appropriate wireless communication technology is important to provide effective solutions.

III. Channel Model And Link Performance

Accurate channel models are extremely important for the design of communications systems. Knowledge of the features of the channel provides communications system designers with the ability to predict the performance of the system for specific applications. The aim here is to study in more details the characteristics of the propagation and performance of channel in an underground mine and to provide insight for future channel modelling works and IIoT deployment strategies.

The effects of multipath propagation in underground mines and subway tunnels on cellular frequencies were studied in [12]. Comparison of experimental results with simulations showed that the generally nonflat boundary of subway tunnels has a major impact on the propagation behavior [11]. The underground mine environment is much like the subway tunnels and the channel characteristics are comparable. These studies show that strong multipath environment affects LPWAN link performance. LPWAN technologies particularly LoRa and NB-IoT are chosen for the underground mine IoT network it supports long-range communication with low power [13]. The LoRa chirp pulses are very resistant against disturbances. Both the technologies are mostly immune to multipath signals. However physical phenomena, like multipath reflection, scattering, and diffraction along the mines' rough walls will affect the propagation of electromagnetic waves [11] [12].

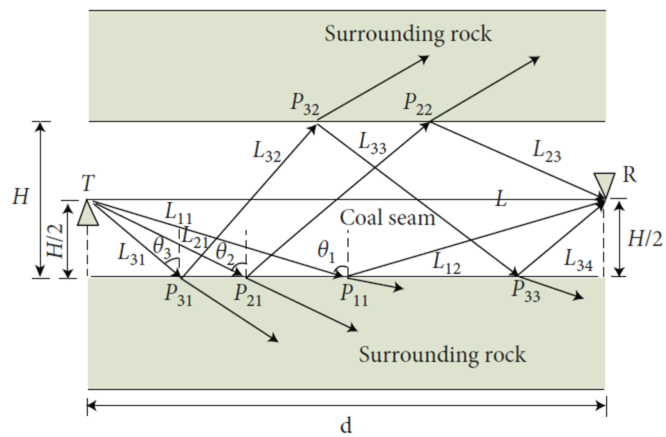

Fig. 2. Diagram depicting multipath signals that undergo reflection from surrounding walls [19]

In underground mine environment the waves undergo reflection, refraction, and transmission characteristics results in a multipath effect. Under the influence of this effect, the signal is transmitted via various paths to reach the receiving end. Multipath propagation creates two problems: fading and dispersion. Meanwhile, channel path losses cause signal fading. In particular, the multipath fading caused by signal reflection, which may vary greatly, may change the transmitted signal/message. As shown in Figure. 2, multiple reflections are possible for a single wave. Path difference occurs among multipath signals at the time of propagation of channel waves in a mine environment, causing signal delay. Multipath fading develops as a result of the multipath propagation of channel waves at the time of reception of the signal by the receiver. This can have a significant impact on the received signal's quality. Several factors cause the attenuation and loss of channel wave propagation within an underground mine. The main factors include dielectric absorption loss due to the incomplete elasticity of the walls, and interface reflection loss due to channel wave reflection through the mechanical properties of the surrounding walls [19].

Very few works have been done to investigate the effect of multipath in LPWAN link performance. In [7], the authors measured LoRa packet error rates (PER) performance in various areas such as city, countryside, and suburb and the results are compared with the theoretical channel model of LoRa that considers propagation attenuation, shadowing effect, and multipath fading. In [16], the authors measured the LoRa PERs in test chambers and the test chambers are designed to simulate the AWGN and multipath propagation environments. The PER performance for various factors such as bandwidth, code rate, and spread factors (SF) were evaluated. The performance of NB-IoT in terms of Block Error Rate (BLER) in a Rayleigh channel was modelled and studied in [20].

IV. Simulation Analysis

A. Techniques

Simulations are best way to measure the performance due to factors like low cost, faster and flexibility to adapt different environments and constraints. Downside is that it might not always be the accurate measure of performance. Empirical data collected with the actual equipment along with the simulation results will provide a better model and accurate measure of performance.

B. Channel description

Underground mines rough walls often affect the performance of wireless communication by reflection, scattering, and diffraction of signals. Rayleigh fading models assume that the magnitude of a signal that has passed through a channel will vary randomly, or fade, according to a Rayleigh distribution. Rayleigh fading is most applicable when there is no dominant propagation along a line of sight (LOS) between the transmitter and receiver. If there is a dominant line of sight, Rician fading may be more applicable. Rayleigh fading is a reasonable model when there are many objects in the environment that scatter the radio signal before it arrives at the receiver. The requirement that there be many scatterers present means that Rayleigh fading can be a useful model in underground mines where there is little to no line of sight between the transmitter and receiver and many objects attenuate, reflect, refract, and diffract the signal. Experimental work carried out in Berlin subway tunnels [11] has found near-Rayleigh fading. In underground mine signal propagation, the walls of the tunnels act as scatterers and this kind of environment also approximates Rayleigh fading. The devices in the mine environment rarely have a LOS transmission or reception. Hence considering a non-line of sight transmission and receiver receiving multiple copies of transmitted signal due to reflections, diffractions and scattering, the behavior encompasses time-variant fading, which are best modelled as a *Rayleigh* distribution.

C. Simulation Analysis

LPWAN system models were developed in MATLAB© and using its LTE toolbox to investigate the effects of strong multipath signals on LPWAN performance. The performance of LoRa in the underground mine environment was studied in detail in [8], this paper uses the results from it directly to compare its performance with the NB-IoT system. The details of the building blocks are not provided in this paper as it has already been explained in [17]. Figure 3 shows the simulation model in a block diagram format.

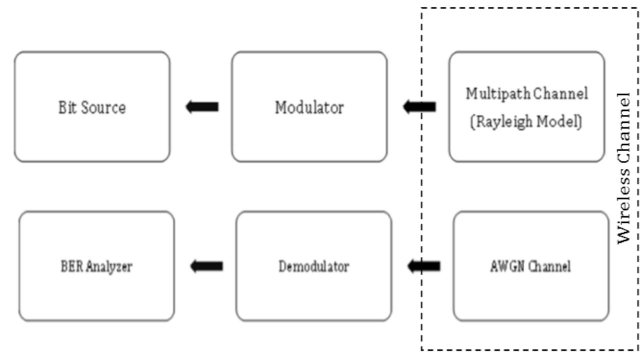

Fig. 3. Simulation model of the LoRa and NB-IoT systems.

The wireless channel model comprises a Rayleigh multipath channel and Additive White Gaussian Noise (AWGN). For LoRa, simulations were carried out with seven multipath components in order to obtain the bit error probability. At the LoRa decoder, the frequency bin which has the strongest component is selected as the symbol [10]. Also, the simulation was carried out with different Spread Factors (SFs). For NB-IoT, simulations were carried out using the LTE Toolbox to create an NB-IoT Narrowband Physical Downlink Shared Channel under multipath fading and AWGN. The simulation length is 4 DL-SCH transport blocks for a number of SNR points. The simulation is performed over different repetition values to compare performance improvement with repetitions.

D. Limitations

The choice of LPWAN depends on various factors such as range, coverage, device lifetime, latency, scalability, payload length, deployment, quality of service, and cost, but these aspects are not investigated in this work. The simulation investigates the effect of multipath fading on the error rate. Change in SF in LoRa and number of repetitions in NB-IoT affects the bit rate. In order to make a comparison in performance, bit rate which is an important criterion must be considered. However, in this paper comparison is done only in terms of reliability of the transmitted signal in terms of bit error rate.

V. Results

Initially, the LoRa model was simulated for SF7 to SF12. Lower SF means more chirps are sent per second; hence, more data could be encoded per second. Higher SF implies fewer chirps per second; hence, there are fewer data to encode per second. Compared to lower SF, sending the same amount of data with higher SF needs more transmission time, known as airtime. In addition, for the lower SNR channels the signal with large SF performs better. This is evident from the result shown in Figure 4. The tradeoff between signal throughput and reliability is crucial in LoRa systems.

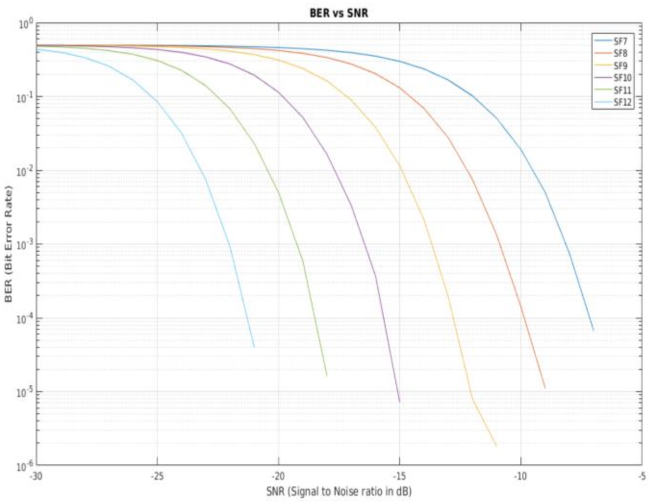

Fig. 4. BER performance of LoRa system with different SFs

The plot of BER vs SNR has negative values of SNR because the signal power level is below the noise level. However, according to the LoRa and NB-IoT specifications, a negative value of SNR indicates the ability to receive signal power below the receiver noise floor [14] [18]. This happens when the communication range is very long and/or the communication channel is affected by large fading and scattering, as in an underground mine environment. This behavior highlights the robustness of LPWAN technology and the possibility to communicate in a very troublesome environment and poor channel with good performances of the communication link.

The multipath channel affects the system BER performance severely compared to the AWGN channel. For example, in Figure. 5, where SF = 7, multipath channel requires 2.5 dB additional SNR at BER = 10-3. As per Figure. 6, where SF = 10, multipath channel requires 6 dB additional SNR at BER = 10-3. The simulation results show that there is approximately 2.5 dB to 6 dB performance reduction compared to AWGN channel with various SFs at BER = 10-3 due to the multipath signals. To achieve good performance under a very noisy channel environment it is important to transmit the signal at higher SF as this proves to perform well under these conditions.

The NB-IoT model was simulated for a number of SNR points and transmission parameters. The system uses inbuilt Rayleigh and AWGN models of the LTE toolbox to estimate the performance of the NB-IoT system. The performance of the system is hugely dependent on the number of repetitions of the transported block which is analogous to the SF in LoRa system. Figure. 7 shows the improvement in the performance of the system with higher repetitions. To achieve the same performance to that of 10-repetition signal, the 1-repetition signal needs an additional 20 dB SNR. On the other hand, increasing the number of repetitions decreases the throughput of the system, which is again similar to the LoRa SF tradeoff. Hence to obtain desired performance, these transmission parameters must be calibrated appropriately.

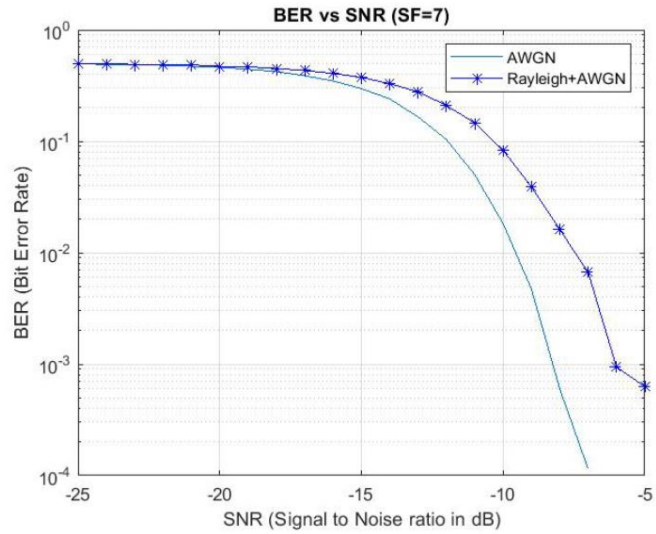

Fig. 5. BER Performance of LoRa System with SF = 7.[8]

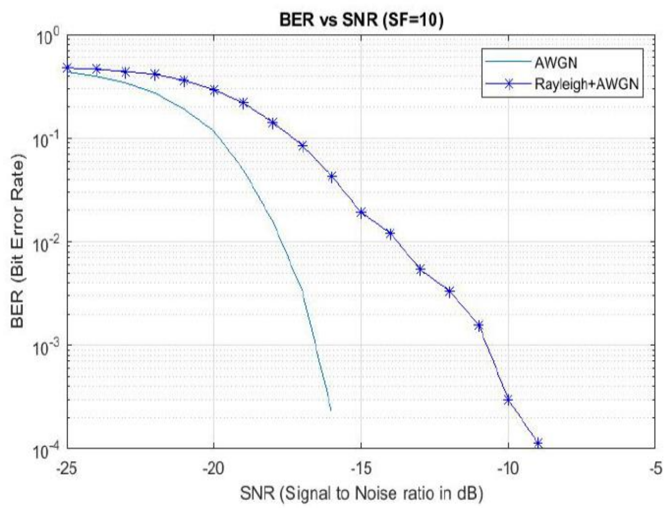

Fig. 6. BER Performance of LoRa System with SF = 10.[8]

The multipath channel affects the NB-IoT performance too. The system's BER performance is affected severely compared to the AWGN channel. For example, in Figure. 7, where the number of repetitions = 5, the multipath channel requires 3 dB additional SNR at BER = 10^{-1}. As per Figure. 8, where the number of repetitions = 10, multipath channel requires 6 dB additional SNR to have zero BER. The simulation results show that there is approximately 2.5 dB to 6 dB performance reduction compared to the AWGN channel with various number of repetitions due to the multipath signals. To achieve good performance under a very noisy channel environment it is important to transmit the signal at higher repetition as this proves to perform well under these conditions.

Moreover, it is important to notice that NB-IoT system can transmit signals without any error at lower SNRs compared to the LoRa system, this is evident from Figure. 9, where, with 10 repetitions, the system achieves BER=0 at -14 dB. Hence, NB-

IoT has a more reliable connection at the severely noisy channel. This result matches with the results in [11] which suggests using NB-IoT for very low latency and high quality of service.

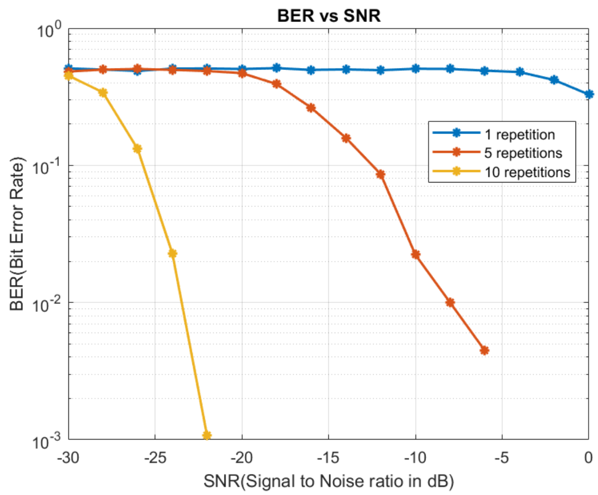

Fig. 7. BER Performance of NB-IoT System with different repetitions.

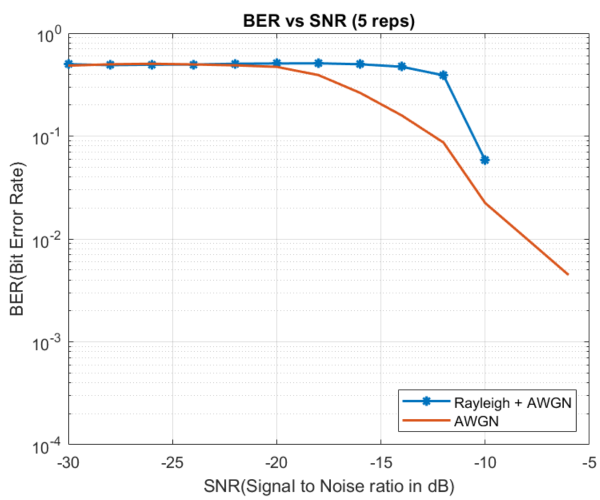

Fig. 8. BER Performance of NB-IoT System with 5 repetitions.

VI. Discussion

Although, the simulation gives an idea of the channel characteristics of the LPWAN technologies, the accuracy of the model is still not adequate for a quantitative comparison. We clearly can't conclude only based on the simulation results that NB-IoT is better than LoRa for underground mine environment. The discrepancy can be due to limitations of the model itself. For instance, the exclusion or underestimation of some factors such as terrain profiles, antenna heights, differences between the environment in analysis and receiver positions.

VII. Conclusion

This paper has detailed the technical differences between LoRa and NB-IoT and discussed their advantages regarding IoT factors and major issues. This study provides design concepts for future implementation of LPWAN in various multipath mine environments. These results will help with the RF budget calculation to get the desired performance in mines. The above

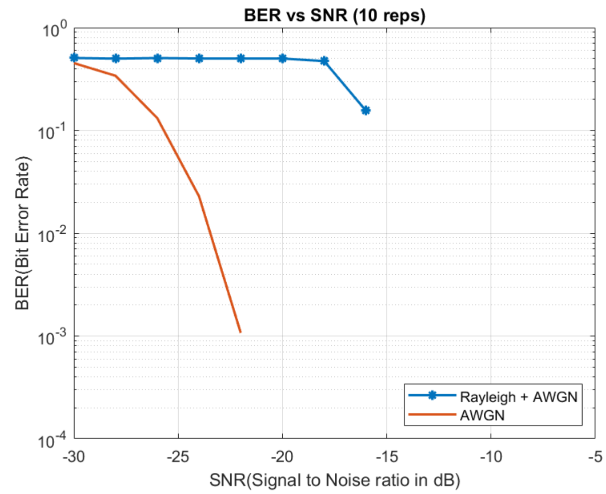

Fig. 9. BER Performance of NB-IoT System with 10 repetitions.

results are from the simulation study and therefore future works include LPWAN performance measurement in a real mine and validate this BER performance study. Each technology has its place in the IoT market. LoRa will serve the lower device cost, very long-range (high coverage), infrequent communication rate, and very long battery lifetime. In contrast, NB-IoT will serve the higher value IoT applications that are willing to pay for very low latency and high quality of service. Finally, it is expected that the 5th generation (5G) of mobile cellular communication will allow an all connected world of humans and devices by the year 2020 [8], which would lead to a global LPWAN solution for IoT applications.

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