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Coded Random Access Technique Based on Repetition Codes for Prioritizing Emergency Communication

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ABSTRACT

This research uses repetition codes based on Coded Random Access (CRA) to support Internet of Things (IoT) to give priority to emergency communications in super-dense networks. Degree distribution for emergency group and general group are obtained with extrinsic information transfer (EXIT) analysis to achieve small error performance shown by the very small gap between emergency group curve and general group curve. This research also evaluates performance by observing throughput and packet-loss rate (PLR) parameters from every groups. Offered traffic in PLR 10^{-2} for emergency group user is G= 0.7 packet/slot without fading and G= 0.65 packet/slot with fading, while for public group is G=0.699 packet/slot without fading and G=0,42 packet/slot with fading. Peak throughput for emergency group is G= 0.737 packet/slot without fading and G= 0.729 packet/slot with fading. Peak Throughput for public group is G= 0.699 packet/slot without fading and G=0.685 packet/slot with fading. Throughput values of emergency group are higher than those of the general group, indicating successful process of giving priority for emergency group.

1. Introduction

There has been increasingly rapid development of information and communication technology indicated with rampant emerging new technologies. The year 2020 sees the 5th generation wireless telecommunication technology (5G) which present a new paradigm of applications involving "things" called Internet-of-things (IoT). Internet of Things consist of devices which have Internet Protocol addresses (IP), are connected to the internet network, and are able to exchange data or information with each other. IoT uses Machine-to-Machine (M2M) Communication which is supported by sensory devices which function like human senses. M2M communications is one of the important elements which will be able to support the future IoT technology. IoT uses broadband communication system when transferring large-sized data, and narrowband communication system when transferring small-sized data.

Having all objects connected to the internet, the number of the world's mobile subscriber was estimated to reach 6.6 billion at the end of 2018 and 9.3 billion at the end of 2019. This figure does not include that of machine to machine (M2M) and 50 billion devices which will be connected with each other. This figure has exceeded the number of the world population which is estimated to reach 8 billion by 2023 as shown in Figure 1 (United Nations, 2020).

Figure 2 shows the usage scenario of 5G technology (IMT-2020). It can be seen that 5G is used not only for broadband communication services, but also services requiring very low latency and massive machine type communications. Massive machine type communications which are the focus of this research mean devices to be connected to the internet network including sensors and radio frequency identification (RFID) the number of which are estimated to reach 10 billion devices, which is larger than the human population. This requires the IoT system to be able to serve more than 1 million devices within 1kilometer radius at the speed of 100 Mbps. This has motivated the development of efficient and effective techniques in wireless communication system, one of which is a research conducted by Anwar (2016b) which proposes the Coded random Access (CRA) technique on the Rayleigh fading channel for super-dense network.

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rate such as light sensors, parking sensors, and the likes because these codes have smaller than 0.5 rate (Abbas et al., 2017).

The degree distribution used in this code is shown in equation (3) and the erasure probability from the UN in the emergency group is expressed as follows:

$$q^d = \sum_{\ell=2}^{n_c} \lambda_\ell^h (p^h)^{\ell-1} \qquad 3)$$

Where,

λ_ℓ^d is the UN fraction on edge-perspective, and erasure probability for general group is q^u.

2.4. System Performance Parameter

To conduct system performance evaluation, the study measures the extrinsic information transfer (EXIT) chart, packet-loss rate (PLR), and throughput.

2.4.1. Extrinsic information transfer (EXIT) Chart

EXIT chart shown two or more representation of overall characteristics and system performance (Purwita & Anwar, 2016). EXIT chat on CRA is determined by UN degree distribution and SN degree distribution, thus it has two curves. Both curves are obtained from edge perspective degree distribution, namely the first derivative $\Lambda(x)$ of $\Omega(x)$ divided by $\Lambda'(1)$ or $\Omega'(1)$.

$$\lambda(x) = \frac{\Lambda\prime(x)}{\Lambda\prime(1)} \qquad 4)$$

while edge perspective of SN degree distribution is

$$\omega(x) = \frac{\Omega\prime(x)}{\Omega\prime(1)} = \exp\left(-\frac{G}{R}x\right) \qquad 5)$$

EXIT chart will present the mutual information, namely

$$I_{E,UN} = 1 - q \qquad 6)$$

and

$$I_{E,SN} = 1 - p \qquad 7)$$

with q is erasure probability from UN and p is erasure probability from SN. The relationship between p and q is expressed in equations 8 and 9.

$$q = \lambda(p) \qquad 8)$$

$$1 - p = \omega(1 - q) \qquad 9)$$

Figure 4 shows an EXIT chart, where the x-axis is UN apriori mutual information and SN extrinsic mutual information, and the y-axis is UN extrinsic mutual information and UN apriori mutual information. The UN curve always starts at point 0, while the SN curve does not start at point 0. The main target of the EXIT chart is to avoid an intersection point between the UN and SN curves before reaching the point (1,1). Performance evaluation is obtained based on the gap between the UN curve and the SN curve. The smaller the gap between the UN curve and the SN curve, the closer the performance to the Shannon limit (smaller error) (Arikan, 2009). The main objective of EXIT chart analysis in this study is to design the optimal degree distribution. This optimal degree distribution is used to produce the optimal performance of the repetition codes.

loss when passing through the frequency-flat Rayleigh fading channel which results in an error-floor, which is a condition when the error does not decrease even though the noise is almost zero. The easiest solution to overcome network congestion is the CRA technique (Hasan & Anwar, 2015).

This research bases on single carrier transmission to keep the system simple because it does not require an equalizer. The modulation used is binary shift keying (BPSK). Repetition codes are designed for communication with very large amounts of data between users and base stations (BS). Repetition codes are very suitable for low data rates which have small transmission speeds, for example on sensors deployed on machines connected to the internet. An example of the structure transmitter for degree d = 3 is shown in Figure 5 where data is transmitted from transmitter with BPSK modulation to superimpose the carrier signal for transmission using three antennas.

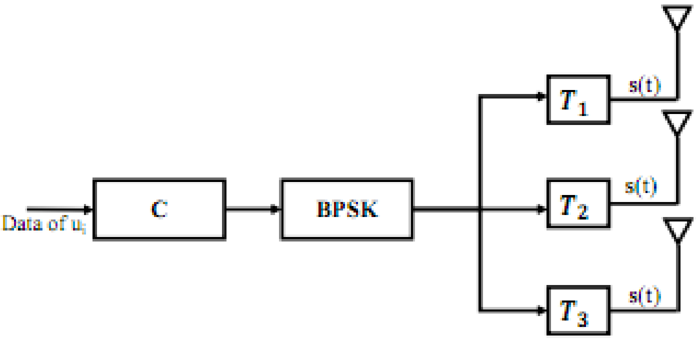

Figure 5. Transmitter for degree $d = 3$.

3.2. Channel Model

Messages or data will be sent using the channel. EXIT chart analysis uses a binary erasure channel (BEC) for easier analysis and the Rayleigh-fading frequency channel for identification of fading.

3.2.1. Binary Erasure Channel (BEC)

Because this research focuses on the network layer, the BEC channel is used in the EXIT chart. In a communication link, there is a possibility that the data received by the receiver contains wrong data (error) (Shokrollahi, 2006). Figure 6 shows BEC with an erasure probability P, which is the probability of data x being lost in the transmission process. BEC has a P value that usually ranges from $0 \leq p \leq 0{,}5$, with the input models of x_1 and x_2 and three outputs of y_1, y_2 and y_3. If a packet "0" is sent, the probability of being received is "e", similar principle also applies for bit "1" (Kythe & Kythe, 2017).

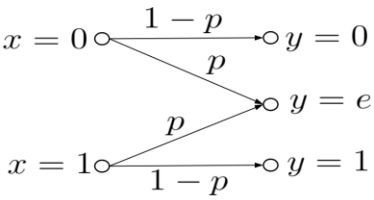

Figure 6. BEC with Erasure probability e

BEC with erasure probability e is shown in equation 12.

$C - 1 - e$…………………………………………………………………………………………..……12)

3.2.2. Frequency-flat Rayleigh Fading Channel

Rayleigh-fading frequency-flat channel is an information channel that contains only one path and the channel follows the Rayleigh distribution with a probability density function (pdf) (Anwar, 2016). Signals passing through the Rayleigh fading frequency-flat channel is received by the model as shown in equation 13.

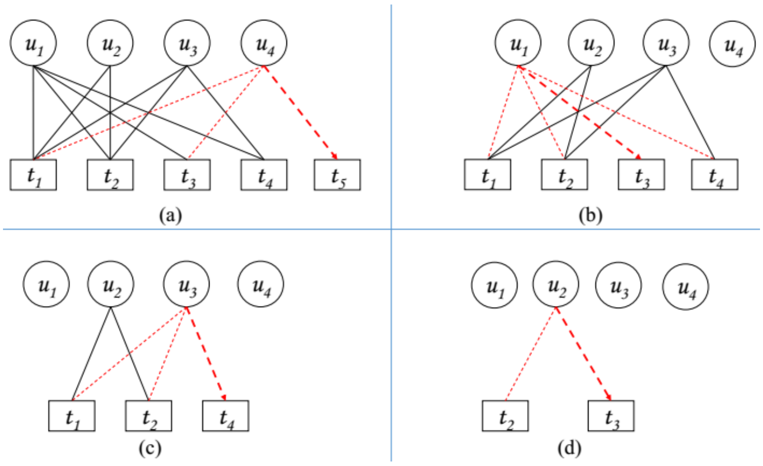

Figure 8. Procedure for decoding performance conducted on BS in super-dense network using repetition codes

The symbols $U_d = \{U_1^d, U_2^d, \dots\dots, U_5^d\}$ indicates the emergency group, the symbols $U_u = \{U_6^u, U_7^u, \dots\dots, U_{10}^d$ indicates the general group, and the total time-slots are denoted by $T = \{t_1, t_2, \dots t_{20}$. To prioritize emergency groups, the emergency group is given freedom to access all time-slots while the general group can only access part of the time-slots. In accordance with the study model (Figure 7), the emergency group can access all 20 time-slots $(t_1 - t_{20})$ and the general group can only access 18 time-slots $(t_3 - t_{20})$. The target of such CRA scheme with priority is to maximize the number of M users. In this study, the number of M users is very large because it involves two groups, while Hasan and Anwar (2015) only involved one group. The total users in this study are the sum of the emergency and general groups $= M_d + M_u$. In CRA, the number of time slots N $(N_d < N_u)$ is minimized to maximize the G (offered traffic) value. In this study, the human and machine group offered traffic (G) can be maximized because it is the sum of the human and machine group offered traffic, in contrast to the research of Hasan and Anwar (2015) which can only maximize offered traffic to one group. Offered traffic on emergency group priority follows Equation 15.

$$G = G_d + G_u \qquad \text{15)}$$

with

$$G_d = \frac{M_d}{N_d} \qquad \text{16)}$$

$$G_u = \frac{M_u}{N_u} \qquad \text{17)}$$

where:

G_d and G_u are emergency and general group offered traffics.
M_d and M_u are number of emergency and general group users.
N_d and N_u are number of of emergency and general group time -slots.

3.6. Degree distribution on User Node (UN) and Slot Node (SN)

Degree distribution is the main characteristic of multiple access CRA techniques. Degree distribution is the distribution of the number of user transmissions and ensures the continuous process of transmission without any errors by using Successive Interference Cancellation (SIC) support on the receiver side. In SIC, there is continuous interference cancellation until a degree of one is achieved, which means that users who are in the time-slot are detected.

Although the slot node cannot be designed and controlled because of the unlimited number of time-slots, a large number of user nodes can be designed and controlled using a degree distribution (Anwar, 2016a). Degree distribution is the distribution of the number of user transmissions which is used to obtain high throughput and to ensure that the SIC can continue running until it reaches a degree of one so that all users can be detected. Degree distribution in the emergency group user node based on the node-perspective is expressed on the polynomial as follows

4. Results and Discussions

4.1. Analysis of EXIT Chart Simulation Results

The study conducts evaluation of multiple access CRA techniques based on repetition codes with 100 users and N=200 time-slots with 50 trials to observe the changes on degree distribution in order to obtain optimum degree distribution. The optimum degree of distribution is a requirement for efficient and high quality results. Optimum degree distribution is obtained through optimization which is expressed in equation 23.

maximizing $G = G_d + G_u,$
parameters $N \leq 200$
$T_d \geq T_u$
$\delta \leq 0{,}1$
$f_{SN}(I_{A,SN}) > f_{UN}^{-1}(I_{E,UN})$ ....23)

where:

N = time-slot
δ = minimum target
T_d and T_u are user throughput (emergency and general)
f_{SN} and f_{UN} are curves from SN and UN EXIT functions

Optimization to give priority to human group is carried out by providing smaller rate and offered traffic to emergency group compared to general group. It is aimed at prioritizing the emergency group to obtain higher throughput values for emergency group than that of the general group. Based on degree distribution optimization, UN degree distribution sub-optimal values for emergency and general groups are obtained using equation 24.

$$\Lambda^d(x) = 0{,}8x^3 + 0{,}2x^7,$$

$$\Lambda^u(x) = 0{,}7x^2 + 0{,}3x^4, \quad \ldots\ldots 24)$$

Based on degree distribution in equation (24), 80 out of 100 users on the emergency group conducted three transmissions to the time-slot randomly. Meanwhile, 20 other users transmitted seven times to the time-slot randomly, resulted in $R_d = 0{,}263$ rate for emergency group users and $R_u = 0{,}387$ rate for the general group users. Seventy out of 100 users in general group transmitted twice to the time-slot randomly and 30 other users transmitted four times to the time-slot randomly. The rate for emergency and general group users is less than 0.5, complying with the repetition codes theory. Offered traffic on emergency group user is $G_d = 0{,}375$ packet/slot $G_u = 0{,}468$ packet/slot for general user group.

Designing optimum degree distribution requires EXIT chart analysis based on UN and SN edge-perspective degree distribution. On EXIT chart for emergency and general group users, CRA time-slots are affected by the emergency group user and general user group iterations. The EXIT curve between the UN-emergency group and the time-slots affected by the general group iteration is called the SN-general group vs SN-emergency group projection. On the other hand, the EXIT curve between the UN-general group and the time-slots affected by the emergency group iteration is called the projection-SN-emergency group vs UN-general group.

This research model channel using BEC channel so that it is assumed that colliding packets will be erased. The EXIT chart is expressed using mutual information for emergency group as seen in equation 25.

$$I_{E,UN}^{d} = 1 - q^d$$

$$I_{A,UN}^{d} = 1 - p^d \quad \ldots\ldots 25)$$

general group are fewer when compared to that of Ni'amah et al (2018). In addition, the emergency and general groups share the same user utility function this study, whereas in Ni'amah et al (2018) the number of human groups is less than the machine (0.1: 0.9). The optimal degree distribution, apart from being influenced by the utility function, is also influenced by fading, where Ni'amah et al (2018) ignore the effects of fading.

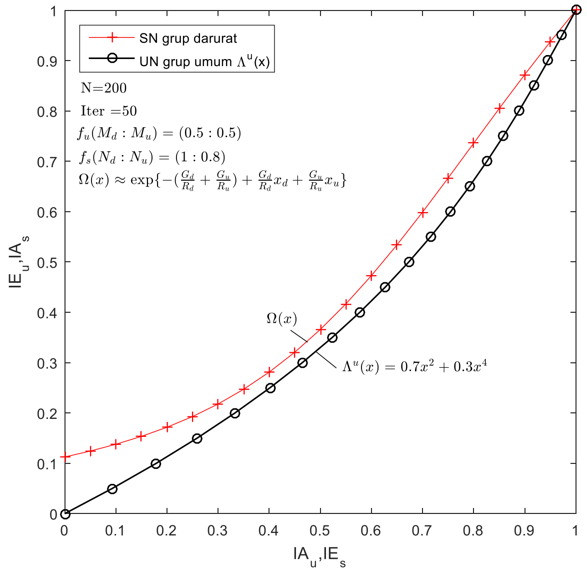

Figure 11. EXIT Chart projection on UN general group to SN emergency group

4.2. Analysis of Packet-loss rate (PLR) simulation results

Figure 12 shows the PLR curve for the degree of distribution $\Lambda^d(x)$, $\Lambda^u(x)$ with N = 200 and the comparison between the number of emergency user groups and general groups is 0.5: 0.5 and the comparison between time-slots used for emergency group user and general group user is : 0.8. Offered traffic obtained on PLR 10^{-2} for emergency group user without fading is G = 0.7 packet/slot and with fading is G = 0.65 packet/slot. Meanwhile, for the general group, offered traffic obtained without fading is G = 0.6 packet/slot and with fading is G = 0.42 packet/slot. It can be seen that the PLR for the emergency group is better than that of the general group, both with and without fading. The analysis results also showed that PLR without fading was better than PLR with fading.

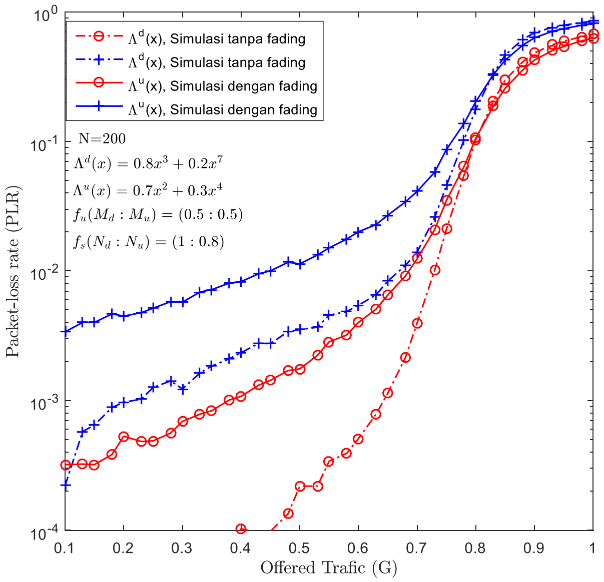

Figure 12. PLR performance graph

4.3. Throughput Simulation results analysis

Throughput can be calculated based on the PLR obtained from equation 11. Figure 13 shows the throughput resulted from the simulation with the number of time-slots (N) of 200. It can be seen that the peak throughput value for the emergency group without fading is G = 0.737 packet/slot and with fading is G = 0.729 packet/slot. Meanwhile, the peak throughput for the general group without fading is G = 0.699 packet/slot and with fading is G = 0.685 packet/slot. It can also be seen that the throughput value for the emergency group is higher than the general group. This shows the success of prioritizing communication in the emergency group compared to the general group.

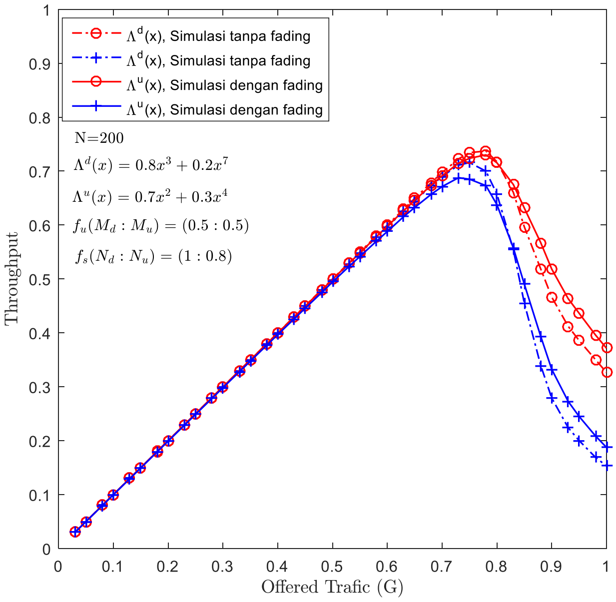

Figure 13. Throughput performance graph

The throughput generated in this study is smaller than thise generated in Ni'amah et al (2018) study because the degree distribution has not reached its optimal level in addition to the effect of fading. This fading effect greatly affects the performance of the CRA technique while Ni'amah et al (2018) ignored this in their study.

5. Conclusions and Recommendations

The CRA technique using repetition codes in this research is very suitable to be applied on super-dense networks on SC-IoT to anticipate the increasing number of communications between devices on the future network. CRA performance is evaluated using the EXIT chart to obtain the most optimal degree distribution in the emergency group and general group, which is identified by the smallest gap on the user node (UN) curve and the slot node (SN) curve. Based on the simulation result curve, EXIT chart shows the degree distribution for the emergency group $\Lambda^d(x) = 0{,}8x^3 + 0{,}2x^7$ and for the general group $\Lambda^u(x) = 0{,}7x^2 + 0{,}3x^4$. This degree distribution performance evaluation can also be seen based on the PLR and the resulting throughput, whether with or without fading effect. Offered traffic on PLR 10^{-2} emergency user group obtained without fading is G = 0.7 packet/slot and with fading is G = 0.65 packet/slot. Meanwhile, for the general group, without fading is G = 0.6 packet/slot and with fading is G = 0.42 packet/slot. Throughput for emergency group without fading is G = 0.737 packet/slot and with fading is G = 0.729 packet/slot. Throughput peak value for general group without fading is G = 0.699 packet/slot and with fading is G = 0.685 packet/slot. The PLR value obtained in the emergency group was better than the general group despite the effect of fading, so that the throughput value in both groups was higher in the emergency group compared to the general group to ensure success in emergency communication. This study has several weaknesses including the user utility function and only one time-slot used. It is recommended that future studies include a more varied comparison of the number of users and time-slots. Another weakness is that the throughput and

PLR values generated in the emergency group have not been maximized. Another method is needed to increase to 0.9 packet/slot.

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