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LTE NETWORK RELIABILITY ASSESSMENT MODELS AND ANALYTICAL EXPRESSIONS

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Abstract– Broadband networks, especially Long-Term Evolution (LTE)/LTE Advanced (LTE-A), are in high demand due to their high-speed wireless data transmission, the coverage of the base stations used, and the complexity of the protocol software. In such cases, the efficiency of the network depends mainly on two important features, which are the reliability and viability of the network. The LTE architecture and network structure should be taken into account to improve reliability and viability. This paper develops reliability assessment models based on the structure architecture of LTE/LTE-A networks. Analytical expressions of reliability assessment based on the developed models are given. In addition, the LTE network is digitally analyzed using these models and analytical expressions.

Key words– LTE/LTE-A networks, reliability, viability, reliability assessment model.

I INTRODUCTION

The advantages of Long-Term Evolution (LTE) and LTE Advanced (LTE-A) technologies are high-speed data transmission, spectral efficiency, and low latency [1]. However, factors such as changes in antenna position, software errors, and changes in the environment, hardware and software failures, and power outages are among the causes of network inefficiency [2]. Improving network reliability and viability in the LTE/LTE-A network, as in all modern systems today, is a key requirement. Understanding the LTE architecture and defining the network structure is important in determining these indicators [3, 4]. [5] presents an analytical model for analyzing the performance of the VANET system for LTE mobile networks. [6] discusses an architecture-based approach to assessing the reliability of software components. This article discusses the processes of component failure, repair, and replacement to analyze the reliability of LTE/LTE-A networks. For LTE/LTE-A networks, reliability attributes such as reliability, availability, and viability were analyzed.

II MATERIALS AND METHODS

LTE architecture. The LTE network is an Internet Protocol (IP) based network that effectively supports packet transmission. The structure of the LTE architecture is shown in Fig. 1.

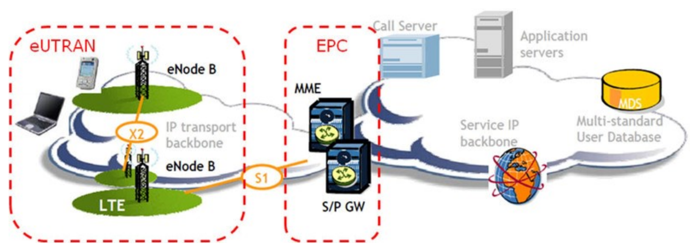

Fig. 1: LTE architecture structure

The LTE system architecture is divided into two parts:

- Evolved Universal Terminal Radio Access Network (E-UTRAN);
- Evolved Packet Core (EPC).

E-UTRAN consists of the following components:

- User equipment (UE). The main function of the UE is to save, add and delete connections, configure the network according to the needs of users;
- NodeB (eNB). eNB is a base station that controls all functions related to radio communication. eNB is distributed across network coverage;
- Mobile main network (Evolved Packet Core - EPC).

Its main functions are to manage mobility and provide security. It consists of the following components:

1. Service Gateway (S-GW). S-GW performs the function of general routing of packets.

2. Mobile Management Entity (MME). Responsible for signaling processes between UE and S-GW.

3. Home Subscriber Server (Mobile Management Entity - HSS).

4. Packet Data Network (PDN) gateway (P-GW). A gateway connects the UE to external packet data networks such as the Internet and IMS4.

To fully describe the reliability attributes of an LTE system, it is important to consider reliability, availability, and viability models simultaneously. To study the reliability attributes based on the LTE architecture, it is necessary to analyze the following features of the system:

- Software architecture;
- Equipment architecture;
- Failure and repair process.

In this study, component failure is considered in terms of reliability or failure rate, the failure of all components is considered independent of each other, and the failure rate and repair rate of the same type of components are the same.

Here are some definitions of the concepts used in the work. Reliability is the ability of a component or network to perform a set of functions under certain conditions for a specific operating time. Mathematically, reliability can be expressed as the probability that a component or system failure time is greater than or equal to the specified time (t):

$$R(t) = P[T \geq t] \tag{1}$$

To model the reliability of the system, it is necessary to determine the probability of failure of components and the state of interconnection of system components [14-16].

Survival is the ability of system components to perform their functions at any time under certain conditions.

We express viability through the following function:

$$X(t) = \begin{cases} 1, & t-time \quad system \quad functions \\ 0, & otherwise \end{cases} \tag{2}$$

In $t > 0$, existence is represented by $A(t)$:

$$A(t) = Pr[X(t) = 1] = E[X(t)]. \tag{3}$$

III Results and Discussions

Defects occur in the LTE system due to the implementation of the handover process, connection errors, failure to ensure uninterrupted power supply [7, 8], and component failure [17-19] [9-13].

The LTE network system consists of two main parts: E-UTRAN and EPC. E-UTRAN consists of eNBs connected to each other via an X2 interface. Each eNB consists of up to three RRHs (Radio Heads) and one BBU (Baseband Unit). RRH is used to transmit and receive wireless signals. The simple structural structure of eNB is shown in Fig. 2 and the relationship between RRH and BBU is shown in Fig. 3.

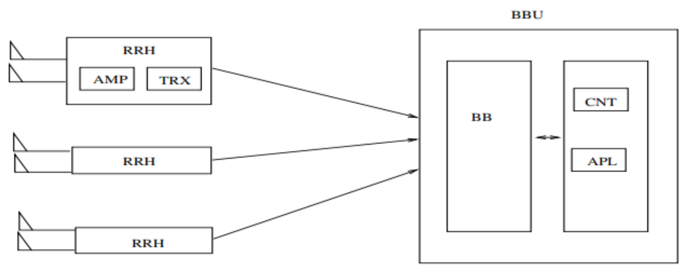

Fig. 2: The simple structural structure of eNB

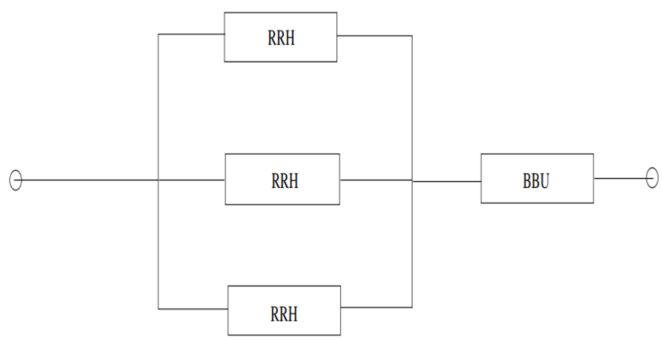

Fig. 3: Structural model of connection of elements on reliability of RRH and BBU system

The total reliability value of the eNB system shown in Fig. 3 is determined by the following expression:

$$R_{eNB}(t) = [1 - [1 - R_{RRH}(t) \cdot R_{BBU}(t)]] = \\ = [1 - [1 - e^{(-\lambda_{RRH} \cdot t)}]^3] \cdot e^{(-\lambda_{BBU} \cdot t)}. \tag{4}$$

Here $R_{RRH}(t)$ – is the reliability of RRH, $R_{BBU}(t)$ – is the reliability of BBU, λ_{RRH} – is the failure rate of RRH, λ_{BBU} – BBU is the failure rate of BBU.

EPC (Enveloped Packet Core) consists of MME, S-GW and P-GW. These components can be interconnected in various combinations:

- The relationship between MME, S-GW as a single component and P-GW as a separate component. This connection is especially useful on 3G networks;
- Bind MME, S-GW and P-GW as separate components. Fig. 4 shows a structural model of the connection of the elements of the system under consideration for this case in terms of reliability.

Fig. 4: Structural model of element connection of MME, S-GW and P-GW in terms of reliability

We enter the following definitions and determine the reliability of the system in Fig. 4 using formula (5). In this case, $R_{MME}(t)$ – MME reliability, $R_{(S-GW)}(t)$ – S-GW reliability, $R_{(P-GW)}(t)$ – P-GW reliability, λ_{MME} – MME failure intensity, $\lambda_{(S-GW)}$ – S-GW failure intensity and $\lambda_{(P-GW)}$ – P-GW failure intensity.

$$R_{ePG}(t) = R_{MME}(t) \cdot R_{S-GW}(t) \cdot R_{P-GW}(t) = \\ = e^{(-\lambda_{MME} \cdot t)} \cdot e^{(-\lambda_{S-GW} \cdot t)} \cdot e^{(-\lambda_{P-GW} \cdot t)}. \quad (5)$$

The reliability of an LTE network depends on the likelihood that the network will support the required functions in the event of a random component failure. Communication between eNBs is important for the reliability of the LTE network.

The viability of an LTE network is the total network bandwidth available to route traffic.

If we assume that all eNBs are the same and their faults differ from each other, the reliability of the LTE network depends on the number of eNBs. Therefore, the more eNBs in a network, the more reliable the network is.

The reliability of an LTE network connected on the basis of a mesh topology, consisting of K eNBs and in the K/2 eNB state, is determined by expression (6).

$$R_{network}(t) = [1 - [1 - (R_{eNB}(t))^2]^{\frac{K}{2}}] = \\ [1 - [1 - e^{(-2\lambda_{eNB} \cdot t)}]^{\frac{K}{2}}] \quad (6)$$

The average LTE network downtime (MTTF) (7) and network downtime (8) are determined by the expressions:

$$MTTF_{network} = \int_0^\infty R_{network}(t)dt \quad (7)$$

$$\lambda_{network} = \frac{1}{MTTF_{network}} \quad (8)$$

IV Conclusion

The reliability of the eNB and LTE / LTE-A network is shown in Fig. 5 and Fig. 6, respectively. These results were obtained on the basis of expressions (4) and (6).

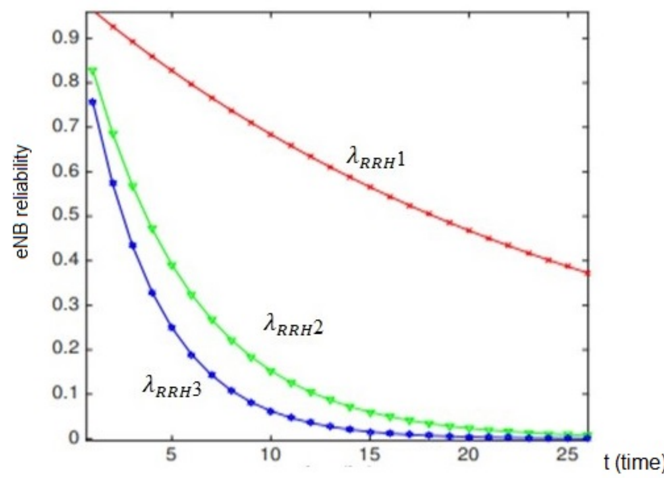

Fig. 5: eNB reliability

$$\lambda_{BBU} = 0.008\frac{1}{hour}, \quad \lambda_{RRH1} = 0.01\frac{1}{hour},$$
$$\lambda_{RRH2} = 0.06\frac{1}{hour}, \quad \lambda_{RRH3} = 0.09\frac{1}{hour}.$$

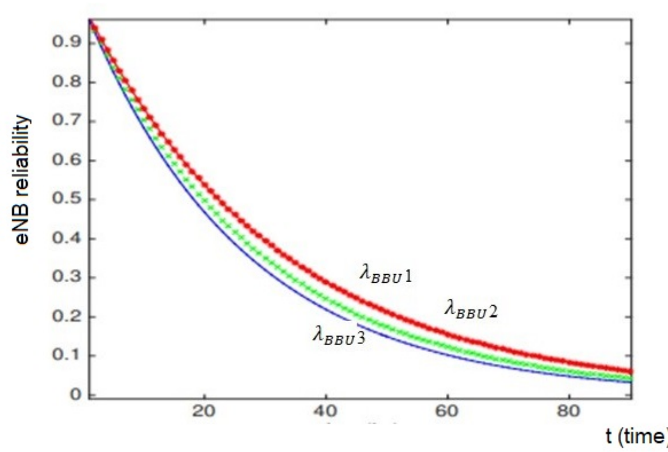

Fig. 6: eNB reliability

$$\lambda_{RRH} = 0.01\frac{1}{hour}, \quad \lambda_{BBU1} = 0.008\frac{1}{hour},$$
$$\lambda_{BBU2} = 0.005\frac{1}{hour}, \quad \lambda_{BBU3} = 0.001\frac{1}{hour}.$$

As can be seen from Fig. 5 and Fig. 6, the reliability of eNB decreases at different values of λ_{RRH} and λ_{BBU} over time.

As can be seen from Fig. 7 and Fig. 8, the reliability decreases as the component failure rate increases. It should be noted that the reliability of the LTE / LTE-A network is significantly affected by changes in the failure rate of the eNB component.

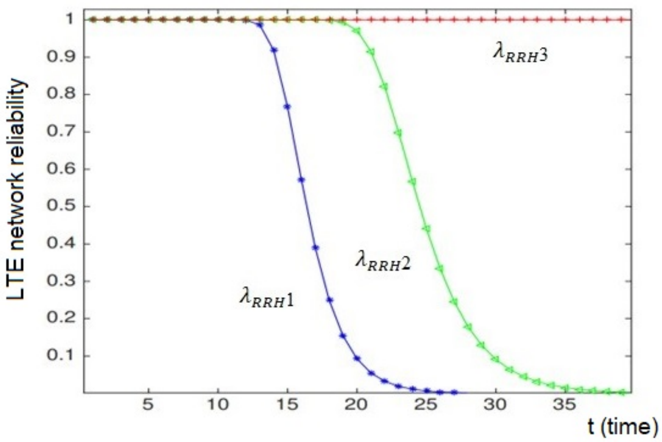

Fig. 7: LTE network reliability

$$\lambda_{BBU} = 0.008\frac{1}{hour}, \quad \lambda_{RRH1} = 0.09\frac{1}{hour},$$
$$\lambda_{RRH2} = 0.06\frac{1}{hour}, \quad \lambda_{RRH3} = 0.01\frac{1}{hour}.$$

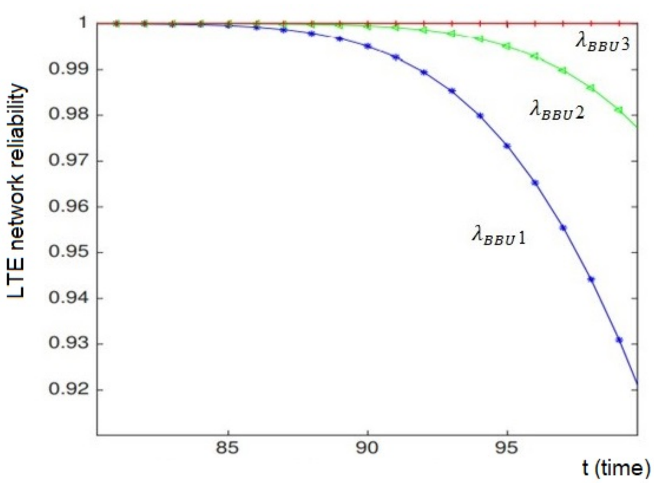

Fig. 8: LTE network reliability

$$\lambda_{RRH} = 0.01\frac{1}{hour}, \quad \lambda_{BBU1} = 0.008\frac{1}{hour},$$

$$\lambda_{BBH2} = 0.005\frac{1}{hour}, \quad \lambda_{BBH3} = 0.001\frac{1}{hour}.$$

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