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MATHEMATICAL MODEL AND CALCULATION OF SS7 RELIABILITY

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ABSTRACT

In this paper, a mathematical model of signaling system seven (SS7) reliability over packet transmission system is developed. The error control model is presented and the SS7 events, states and probabilities are also explained. An expression is derived for all modeled probabilities using transition probability matrix. The reliability parameters are calculated with respect to the derived probabilities of the model and results are critically analyzed and presented for the same.

Keywords: *Mathematical Modeling, SS7 Signaling, Error Control, Reliability, SS7 Probabilities And States*

1. INTRODUCTION

Signaling System Seven (SS7) is a set of protocols and procedures which used in telephony for the management and control of telecommunincation network. SS7 signaling is termed Common Channel Signaling (CCS) in that the path and facility used by the signaling is separate and distinct from the telecommunications channels that will ultimately carry the telephone conversation. With CCS, it becomes possible to exchange signaling information without first seizing a facility, leading to significant savings and performance increases in both signaling and facility usage. Anather binifet from the separation is implementing digital transmission technique and datagram approach to packet switching.

Basic functions of the signaling protocol at the data link layer are flow and error control employing sliding-window technique and monitoring for reliability.

This important function is achieved by ensuring that:

- Transmitted blocks are delivered with no errors, losses or duplication.
- The blocks are delivered in the proper order.
- The receiver is capable of exercising flow control over the transmitted data.

In order to provide these functions, the system contains three types of frames (Fig. 1), called signaling unit SU:

- FISU-Fill In Signal Unit
- LSSU-Link Status Signal Unit
- MSU-Message Signal Unit

All three types share a common syntax that provides error-free transmission of information in the signaling network. These include: Flag, backward sequence number (BSN), BIB, forward sequence number (FSN), FIB, LI. Error control function is provided by the protocols of the second layer of OSI reference model.

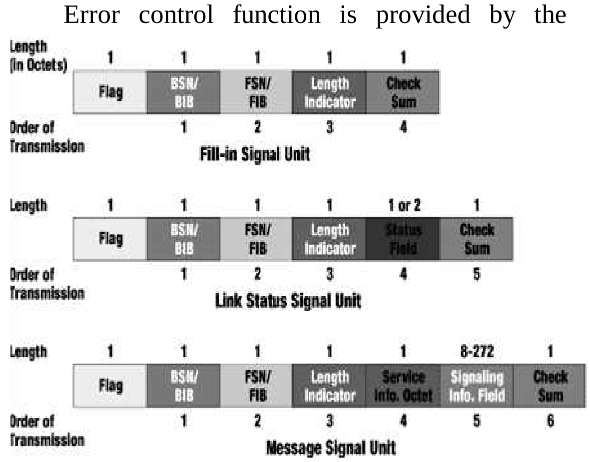

Fig. 1. Three types of SU

Each MSU is given a new FSN, in modulo 128, LSSUs and FISUs not numbered, but carry the last MSU's FSN. All three types of SU can have negative acknowledgements (Nack) and piggybacked acknowledgements (Ack).

In LSSU flow control case, if one side is unable to keep up with the flow of data from

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the other side, busy indication is performed by the status field.

For long congestion, timer control is used. Rules are:

If a receiver becomes overloaded, it must send a busy signal to stop transmission from the other side. The receiver withholds ack of the MSUs. If the overload condition persists, the node must repeatedly send a busy indication at intervals of time (80-120 ms). Other side suspends transmission time of MSUs. When congestion abates at the receiver, the receiver signals the end of busy condition by resuming positive ack of incoming MSUs. Even if repeated busy indications are received in time, a node will report the network level that the link is out of service every (3-6 sec).

The performance analysis aim to serve two main functions [1]:

a) to give the user of national and international digital networks an indication as to the expected error performance under real operating conditions, thus facilitating service planning and terminal equipment design;
b) to form the basis upon which performance standards are derived for transmission equipment and systems in an ISDN connection.

Results of the monitoring SS7 represent management tool for providing new services to subscribers, invoicing transit signaling SS7 and audit the accounts from the operators. Moreover, the availability of SS7 data in real time helps in preventing the emergence of adverse conditions, detection of unauthorized access, estimation of the operator switch functioning, and statistical evidence of quality of service (QoS). All of this explains the importance of SS7 reliability modeling and calculations.

This paper is organized as follows: Sect. 2 devoted for the background literature review, sect. 3 presents error control model, explains the SS7 events, states and probabilities. After, in sect. 4, we derive expressions for all modeled probabilities using transition probability matrix. Sect. 5 presents the calculation results and conclusion.

2. BACKGROUND LITERATURE REVIEW

Reference [2] represents general and common information about SS7, signaling points and signaling links types are discussed, layers and information units also given. The analysis in [2] is limited to the presentation and discussion of functionality and operation of SS7. In [3], a low-complexity H-ARQ SNR gain model that is capable of predicting the SNR gain that using the H-ARQ scheme is defined for Long Term Evolution (LTE). The results of simulation with different parameters are presented. An expression for delay and throughput was found based on Markov model of ARQ, the analytical results were derived for Stop-and-Wait and for Go-Back-N procedures which are less effective and simpler than the selective repeat ARQ in [4]. For the derivation of the formulas used in calculating SS7 reliability, we use the Transition Probability Matrices proposed in [5]. General information about SS7 is provided in SS7 User's Guide [6]. SS7 User's Guide deals with different aspects of SS7 technology; planning; installing; configuration; managing and monitoring SS7. Further information on SS7 functionality is found in [7]. Similar work is published by Min Young Chung and others in [8], Performance Analysis of Common Channel Signaling SS7 Networks is based on Queuing Network models to evaluates the mean end-to-end delay of a single-mated pair CCSN for various call-arrival rates in a normal state and several failure states, as a performance index. As a performability index, [8] also analyzes the mean time to unreliable operation of a given network for various call-arrival rates at each signaling end point and the failure rate of each signaling transfer point.

In [8], failure rates are considered to be constant for the simplification of analysis, further more; in the Queuing Network model, a small number of calling nodes are considered.

3. ERROR CONTROL MODEL

ITU-T recommended the implementation of two error control methods: Basic method and Preventive cyclic retransmission method. The idea of error control by the basic method which used in SS7 is similar to the idea, realized in the HDLC procedure. Basic method applies for signaling links where one-way propagation delay (PD) is less than 15 ms. Basic method is simply a go-back-N ARQ. Briefly the idea is as follows:

- Each SU is given a new FSN, in modulo 128 after every transmission,

- BSN is used to acknowledge received signal units.

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- By FIB, the information a bout SU if retransmitted or not
- Positive or negative acknowledgment (ACK or NACK) for the transmitted SU is presented in the BSN and BIB of SU that backward transmitted.

Positive ack which transmitted from remote node indicates that SU is received without error; otherwise negative acknowledgment is transmitted, requesting the retransmission of SU. Signaling link must prevent the loss of SU. If channel impairment occurs, it leads to distortion of the SU. To prevent the loss of SU both sides of the CCS should be in-phase state.

Control states, the transmission or retransmission of SU can be fixed when reading the Signal Trace taken from the Management

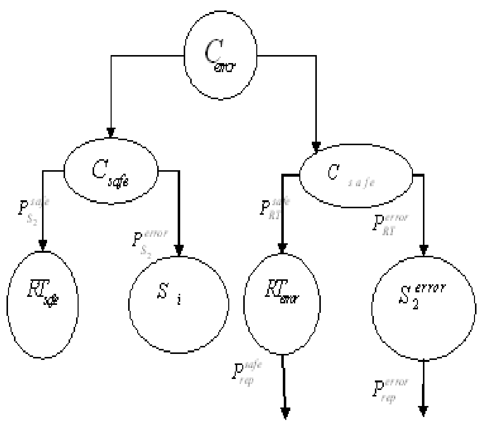

Fig. 2. Observed events of SU

Node. Therefore, these are states that observed during the operation. For collecting and processing of statistical data we can run counter for each type of message on all lines. These counters provide real statistics on the call QoS.

The transmitting signal point keeps all transmitted SUs in a buffer until acknowledged. Once the BSN is received, all acknowledged SUs are dropped from the buffer. Unacknowledged SUs stay in the buffer until a timer expires, causing a link failure indication to be sent to Level 3. The link is then tested and aligned.

We model the error control procedure making a focus on the probabilities of transition from state to another and the impact of these probabilities on the QoS.

Transition state model is proposed to consider all probabilities of a SU procedure. Fig. 2 shows the following states: $C_{initial}$ – Initial state of signaling information source; C_{safe}, C_{error} – Check states is without error and with error accepted SU; S_2^{safe}, S_2^{error} – states of transmission of next SU without error and with error accepted SU; RT_{safe}, RT_{error} are states of SU Retransmission without error and with error accepted SU; and the following probabilities: $P_{S_2}^{safe}$, $P_{S_2}^{error}$ the probability of falling in state S_2 without error and with error accepted SU; P_{RT}^{safe}, P_{RT}^{error} the probability of falling in state RT without error and with error accepted SU; P_{rep}^{safe}, P_{rep}^{error} the probability of repeating the procedure without error and with error accepted SU.

Errors in channel with feedback lead to the loss of information, called "inserts" and "losses". Inserts are obtained in cases when the receiver sends an ACK signal to the feedback channel; this signal is transformed into a request signal. In this case, the transmitter retransmits the previous frame, and the receiver sees it as the next, the same information is transmitted twice (control error type 1). A loss obtained when the receiver sends a request signal and this signal is transformed into an Ack. In this case, via a direct connection the transmitter sends next frame, but the previous one is erroneously received (control error type 2). Since the system operates as a system with feed back channel here also there are inserts and losses, which lead to lower QoS in system where it is assumed that can support up to 1,500 voice channels.

The scenario described here is simulated in the developed mathematical model (Fig. 3). The mathematical model takes into account the fact that the transmitted SU may be distorted due to the insufficient quality of the used communication channel and due to a large amount of transmitted information. The proposed mathematical model is designed for only one part of the network, without taking into account the structure and topology of the network.

The following assumptions were made in the model: channel of SS7 are in continuous use; all events occur at random times; the distribution of time between events is exponential.

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In the described model we consider the following states of the signaling system: S_i - initial state of signaling information source; S_{safe} and S_{error} - states with safely and erroneously received SU; ACK_{safe} and ACK_{error} - the state of sending ACK signal for safely and erroneously accepted SU; Req_{safe} and Req_{error} - the state of sending request signal for safely and erroneously accepted SU; S_{next}^{safe} and S_{next}^{error} - the state of sending next SU after safely and erroneously accepted SU; in the case of S_{next}^{error} we observe the loss of information; RT_{safe} and RT_{error} are states of Retransmission of safely and erroneously accepted SU.

Transitions between state are characterized by the following probabilities: α - probability of error of SU; $(1-\alpha)$ - probability of safe accepting of SU; γ - probability of transformation of the ACK signal to the request signal (control error type 1); $(1-\gamma)$ - probability of sending ACK signal after safely accepting SU; β - probability of transformation of the request signal to the ACK signal (control error type 2); $(1-\beta)$ -probability of requesting erroneously accepted SU; P_{RT}^{safe} and P_{RT}^{error} -probabilities of retransmission of safely and erroneously accepted SU, $P_{RT}=1$; P_{next}^{safe} and P_{next}^{error} - probabilities of sending next SU after receiving ACK signal of safely and erroneously accepted SU, $P_{next}=1$.

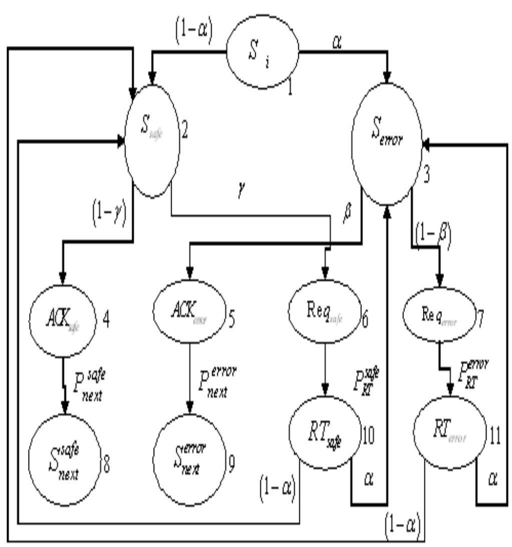

Fig.3. Mathematical model of transition probabilities

4. DERIVATION OF EQUATIONS

These probabilities present the process of state transition, thus we return to them as transition probabilities. These probabilities can explain the characteristics of described events. To derive the formulas of calculating of the reliability we use the Transition Probability Matrices proposed in [5]. For this purpose we form full transition probability matrices of states and then perform its partition to the 7the state (state numbers are shown) as shown in Fig.4 (a), (b), (c), (d).

As the input subset $U^+=\{S_i\}, i=1$ contains only one state then the relative frequencies of the states of the set U in the stationary mode are elements of the first row of the matrix of relative frequencies $N_U=E-P_{UU}$.

Thus, we obtain formulas for calculating the following probabilities:

$$\left.\begin{aligned} P\left(S_1,S_{next}^{safe}\right)&=(1-\gamma)(1-\alpha);\\ P\left(S_1,S_{next}^{error}\right)&=\alpha\beta;\\ P\left(S_1,RT_{safe}\right)&=\gamma(1-\alpha);\\ P\left(S_1,RT_{error}\right)&=\alpha(1-\beta). \end{aligned}\right\} \quad (1)$$

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$$P_{Uv}=\begin{array}{c} \\ 1\\2\\3\\4\\5\\6\\7\end{array}\begin{array}{cccc} 8 & 9 & 10 & 11\\ \hline 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0\\ P_{next}^{safe} & 0 & 0 & 0\\ 0 & P_{next}^{error} & 0 & 0\\ 0 & 0 & P_{RT}^{safe} & 0\\ 0 & 0 & 0 & P_{RT}^{error}\end{array}$$

(a)

$$P_{UU}=\begin{array}{c} \\ 1\\2\\3\\4\\5\\6\\7\end{array}\begin{array}{ccccccc} 1 & 2 & 3 & 4 & 5 & 6 & 7\\ \hline 1 & 1-\alpha & \alpha & 0 & 0 & 0 & 0\\ 0 & 1 & 0 & 1-\gamma & 0 & \gamma & 0\\ 0 & 0 & 1 & 0 & \beta & 0 & 0\\ 0 & 0 & 0 & 1 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 1 & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & 1 & 0\\ 0 & 0 & 0 & 0 & 0 & 0 & 1\end{array}$$

(b

$$P_{vU}=\begin{array}{c} \\ 1\\2\\3\\4\end{array}\begin{array}{ccccccc} 1 & 2 & 3 & 4 & 5 & 6 & 7\\ \hline 0 & 1-\alpha & \alpha & 0 & 0 & 0 & 0\\ 0 & 1-\alpha & \alpha & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & 0 & 0\end{array}$$

(c)

$$P_{UU}=\begin{array}{c} \\ 1\\2\\3\\4\end{array}\begin{array}{cccc} 1 & 2 & 3 & 4\\ \hline 1 & 0 & 0 & 0\\ 0 & 1 & 0 & 0\\ 0 & 0 & 1 & 0\\ 0 & 0 & 0 & 1\end{array}$$

(d)

Fig.4. transition probability matrix of states (a), (b), (c), (d).

The obtained probabilities are linearly dependent and represent the percentage of hits in state, corresponding to one signaling unit. Derivation of the obtained formulas been done without taking into account the retransmission of the SU. The task of identifying the probability of SU in the retransmission state can be solved by dividing the full Transition Probability Matrices (see Fig. 4. (c) (d)) to 8th state.

For this case we found formulas of dependence of the average number of retransmissions for one SU on the probability of transformation of request signal and the Ack signal, and also on the probability of SU distortion:

$$\left.\begin{aligned} &P\left(S_1,S_{next}^{safe}\right)=(1-\alpha);\\ &P\left(S_1,S_{next}^{error}\right)=\frac{\beta(1-\gamma\alpha)}{(1-\gamma)};\\ &P\left(S_1,RT_{safe}\right)=\frac{\gamma(1-\alpha)}{(1-\gamma)};\\ &P\left(S_1,RT_{error}\right)=\frac{(1-\alpha\gamma)}{(1-\gamma)}.\end{aligned}\right\} \qquad (2)$$

By using research results and compared them with observed characteristics, we obtain the following system of equations:

$$\left.\begin{aligned} &P_{next}^{safe}=(1-\gamma)(1-\alpha);\\ &P_{next}^{error}=\gamma\alpha;\\ &P_{RT}^{safe}=\gamma(1-\alpha);\\ &P_{RT}^{error}=\alpha(1-\beta).\end{aligned}\right\} \qquad (3)$$

The system of equations (3) may be rewritten as:

$$\left.\begin{aligned} &1-\beta=\frac{P_{RT}^{error}}{\alpha};\\ &1-\alpha=P_{RT}^{safe}+P_{next}^{safe};\\ &\gamma=\frac{P_{RT}^{safe}}{(1-\alpha)}.\end{aligned}\right\} \qquad (4)$$

For the second case when considering retransmissions we obtain:

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$$\left.\begin{aligned} P_{next}^{safe} &= (1-\alpha); \\ P_{next}^{error} &= \frac{\beta(1-\gamma\alpha)}{(1-\gamma)}; \\ P_{RT}^{safe} &= \frac{\gamma(1-\alpha)}{(1-\gamma)}; \\ P_{RT}^{error} &= \frac{(1-\alpha\gamma)}{(1-\gamma)}. \end{aligned}\right\} \quad (5)$$

The system of equations (5) is rewritten in a suitable form as:

$$\left.\begin{aligned} \gamma &= \frac{1-P_{RT}^{error}}{\alpha-P_{RT}^{error}}; \\ \beta &= \frac{P_{next}^{error}}{P_{RT}^{error}}; \\ 1-\alpha &= P_{next}^{safe}. \end{aligned}\right\} \quad (6)$$

5. CALCULATIONS AND CURVE RESULTS

A number of reliability parameters affect the performance of the SS7 protocol. In [4] an expression for delay and throughput was found based on Markov model of ARQ, the analytical results were derived for Stop-and-Wait and for Go-Back-N procedures. Here we conclude some key-parameters in our model.

- Bandwidth (B): it is the maximum amount of data passing the channel at a given time. Usually, it depends on the medium capacity of the communication channels itself.
- Processing time of a frame (T_s): it is the time it takes for a frame to send/receive to/from the channel.

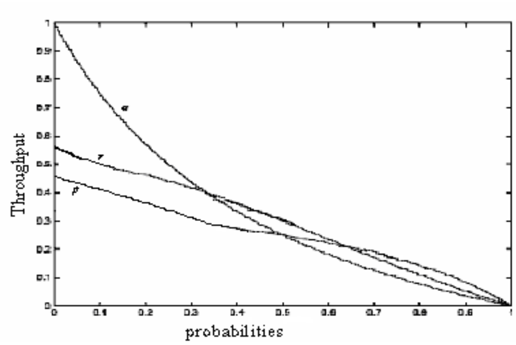

Fig. 5. Throughput with respect to derived probabilities

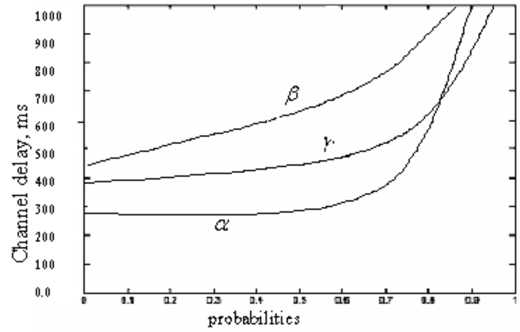

Fig. 6. Channel delay with respect to derived probabilities

- Channel delay and round trip time (T_r): channel delay is the time it takes for data to travel across the channel. Round trip time is the time it takes for data to travel across the channel from the sender to the receiver and then back. In our model, we suppose that the channel delay of the data frames and acknowledgement frames have the same normal distribution with $\mu = T_r/2$ for various variance σ. Let σ has different values such as 0.1^*T_s, 0.2^*T_s or 0.5^*T_s.

The calculations of the derived probabilities with respect to throughput of SS7 channel and results presented in fig. 5. Curves in figure explicitly show the change in system throughput for different procedures: considering only α; then taking into account γ, here of course with α; then β that become after α and γ. For the first curved line in figure, if $\alpha = 0$ then no errors in system and of course no retransmissions then we obtain maximum throughput, when $\alpha = 1$ this means that each frame is transmitted with error that makes system throughput drop down with increasing α.

With increasing γ which is the probability of transformation of the ACK signal to the request signal the throughput decrease to minimum value as obtained in the curved line denoted by γ.

Similar discussion is applied to the dependency of system throughput and β the probability of transformation of the request signal to the ACK signal.

Generally, we denote that control error type 1 and 2 dramatically affect system throughput and SS7 functionality, which in turn degrade the QoS. Trade-off must be found between increasing probability to reduce error rate and decreasing system throughput and data rate,

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here we propose the probability values from 0.3 to 0.7 to have 30% of system throughput.

These probabilities affect the SS7 channel delay as presented in fig.6. The same probabilities α, γ, β are considered. Channel delay in (ms) increase rapidly with increasing probability values which is expected by the error and retransmissions. Here to make channel delay no greater than 400 ms, then α to be less 0.7.

These results can be used in the design and improvement of common-channel signaling networks.

REFRENCES:

[1] Recommendation G.821 (08/96) Transmission Systems and Media, Digital transmission systems–Digital networks–Quality and availability targets.

[2] Riaz S.S." Performance Analysis of Signaling System 7(SS7) Network and Protocols to Provide Call Control, Remote Network Management and Maintenance Capabilities" Journal of Theoretical and Applied Information Technology, www.jatit.org, PP. 136-142, Vol. 5. No 2. – 2009

[3] Josep C., Martin W., Markus R. "Performance and Modeling of LTE H-ARQ" EURASIP, WSA, Berlin 2009

[4] Yong Ho Kim, Tae Yong Kim, Young Yong Kim "A Novel Approach for Modeling a Hybrid ARQ (Automatic Repeat ReQuest) Based on the Hidden Markov Model" IEICE Tranc. Commun. Vol. E88-B, No.9, 2005

[5] José J. Ortiz-García; Seósamh B. Costello; and Martin S. Snaith "Derivation of Transition Probability Matrices for Pavement Deterioration Modeling" Journal of Transportation Engineering, ASCE / Feb. 2006 / 141.

[6] SS7 User's Guide, SS7 Support for WebSphere Voice Response, IBM, Ver. 6.1 http://publib.boulder.ibm.com/infocenter/wvraix/v6r1m0/topic/com.ibm.wvraix.newss7.doc/dtxnewss7.book.pdf

[7] "SS7 tutorial" http://pt.com/page/tutorials/ss7-tutorial

[8] Min Young Chung and others, Performance Analysis of Common Channel Signaling Networks, Based on Signaling System #7. In IEEE Transactions on Reliability, vol. 48, no. 3, 1999 September. 0018-9529/99

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