A Survey on Voice over Internet Protocol (VoIP) Reliability Research

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Abstract. VoIP technology deals with the real-time data communication for voice transfer in the form of digital packets through internet communication and facilitates public to make use of internet for video and phone calls. The voice data packets are transferred from source to the destination and vice versa. VoIP require high speed internet connection for data transfer on data network. It is necessary to arrive the data packet from its source to the destination with high level of reliability. It is very important to analyse link failure, packet loss, delay and jitter during the data communication. Components involved in data communication should be reliable. This paper provides a survey for step wise development and use of reliability techniques for gaining high quality of voice in VoIP network.

Keywords: VoIP, Reliability, availability, QoS

1. Introduction
VoIP technology deals with the real-time data communication for voice transfer in the form of digital packets through internet communication. The voice data packets are transferred from source to the destination and vice versa. For the purpose of communication of data between two nodes, first the voice signal which is in the analog form is converted to digital form as data packets then sent over the internet using codec. The process is repeated at the receiving end but in reverse order, first digital data is converted to analog signal then communicated to the destination node [1]. VoIP is a component based system which handle critical applications and evaluation of reliability and security of this becomes very important [2].

1.1. PSTN Vs VoIP
Public Switched Telephone Network (PSTN) is the oldest communication service for providing end to end switched circuit communication for voice signal transfer for more than a hundred year. With the advancement of data networks, the service is being avoided because of its cost and data transfer inefficiency. Voice and data transfer over the same network becoming popular because of involvement of less communication infrastructure like cables, exchange branch etc. which ultimately reduces cost, this encouraged the people to use VoIP [3].
1.2. Architecture of VoIP
Making a phone call using broadband internet connection with packet switching network is very fast and cost saving. VoIP is the best known for transfer of audio and video using packet network. The architecture of VoIP differs from PSTN. There are some differences like centralization of audio services which is possible only by using VoIP systems [4]. The voice transmission in VoIP network is shown in Figure 1.

![Figure 1. Voice Transmission in VoIP Network.](image)

This paper is organized in four sections, introduction part covers introduction to VoIP along with architecture of VoIP. Literature survey is presented in section 2 along with year wise reliability analysis techniques in table format. Further, section 3 describes about reliability of VoIP, reliability matrices and reliability issues in VoIP system. Finally, section 4 concludes the paper.

2. Literature Survey
Authors surveyed the VoIP challenges, discussed about the implementation with some factors considerations, protocols requirements and necessary components for connection set up [5]. The researchers surveyed VoIP technology with brief introduction. They discussed about protocols, jitter, delay, loss of packet and feasibility of this technology over the satellite links [6]. Modelling and computation for availability was performed on the basis of corresponding signalling and bearer path. They have shown accuracy of Simplified Availability Modelling Worksheet (SAMOW) after comparison with Markov model [7]. Authors investigated performance and dependability modelling for services engaged in transfer of audio data and used Stochastic Petri Net (SPN) for modelling approach and evaluated the dependability of audio data communications [8]. Worked on end to end service reliability for VoIP and developed models for network elements like links, routers, switches gateways, call servers [9]. Highlighted the development of soft switches for Voice over Internet Protocols and Asterisk (PBX) free software tested as fault tolerant and had shown the possibility of improvement of the service availability [10]. Presented widely-used concept of fault-tolerance and found that mapping a design at system level is possible for Quality of Service performance like fault-tolerance needs at the level of application compared to Open System Interconnection (OSI) model [11]. Research covers the issues of Voice over IP impacting the reliability and integrity and described, delay, packet loss, and jitter. Moreover, analysed the hardware component level reliability by using Markov Model [12]. Presented the Voice over IP architecture on the basis of node to node rules. The
peer-to-peer technology is applied by integrating load balancing and requirements for failover [13].
Surveyed recent areas for routing protocols developments. Quality of Service (QoS) techniques, packet related mechanisms, standards for wireless communication and further surveyed QoS parameters affecting the quality of audio or video in voice over IP communication in wireless mesh networks e.g. loss of packet, jitter and delay [14]. Presented modelling for packet loss which is one of the QoS parameters and performed analysis for jitter and packet loss for VoIP traffic [15]. Proposed Gilbert–gamma topology for packet-loss in speech quality transmitted over Internet Protocol (IP) networks. In the topology, they shown introduction of packet-loss process for the speech recognition systems in VoIP [16]. Evaluated algorithms for the purpose of analysis of reliability and availability of VoIP. The methodology was based on IP Markov at component level and constituted tools for reliability and availability of complex networks [17]. Evaluated availability for VoIP networks services in internet using measurement data and metrics for availability [18]. Proposed Rapid Availability Prototyping for Testing Operational Readiness (RAPTOR), a software tool for gaining availability during life cycle [19]. Utilized a network simulator known as OPNET Modeler 14.5 for reliable VoIP network and assured the gain of network reliability [20]. Proposed SATCOM (SATellite COMMunication) links as reliable and efficient way to transmit IP data for voice communication and as a backup transmission link for overall resilience improvement [21]. Proposed a hierarchical model by combining performance and reliability, failure of more than one component was considered for modelling reliable VoIP network in wireless environment. Markov chain was utilized for constructing a reliability model and reliability metrics like Mean Time To Failure (MTTF) is recorded in VoIP network [22]. Proposed an approach for Voice over IP and discussed challenges. Lagrange’s interpolation was applied for reliability and fault tolerance. But for effective stego-message communication reliability issues need addressing [23]. Reviewed PSTN for five nines reliability and observed the achievement of same level for voice over IP. Using Linux open source, they experimented for providing higher level of availability. But the work is in continuation for theoretical analysis of availability [24]. Explored VoIP for transport protocols and presented a Reliable Signalling Transport Protocol (RSTP). They presented RSTP advantages for reliability. But in this direction an efficient algorithm is required [25]. Studied the main VoIP components like servers, firewalls, routers etc., which can affect the VoIP service. The modelling used Continuous Time Markov Chain (CTMC) for software rejuvenation and was used for reliability and availability analysis in two cases one with rejuvenation and other without rejuvenation [26]. Followed Markov process for degraded states in modelling software rejuvenation in a VoIP system. Moreover, checking the control states triggering for rejuvenation was tested [27]. Presented an easy-to-use software tool, called NetExpert. The reliability and availability model were used in the software. They presented a comparative analysis of network topologies for fiber network and found NetExpert as tool for the design of different network configurations [28]. Proposed an E-model for Thai environment and presented solution for delay in packet transfer. They defended E-model for reliability and accuracy. The authors suggested the findings as latest evidence for language identification in VoIP system. But only Thai voice samples were considered, moreover this bias factor need further investigation [29]. Presented reliability evaluation of business VoIP proposed an approach which identified two VoIP design one about reliability standards and secondly matrices for measurement of enterprise VoIP services [30]. Mentioned about VoIP reliability including IP networking infrastructure. Reliability matrices at element and service level was mentioned. Authors found matrices as an essential requirement tool for measurement of VoIP reliability [31]. Measured and evaluated QoS for Voice over IP (VoIP). Mean Opinion Score (MOS), latency, packet loss and jitter remained the main criteria for evaluation [32]. Detected link failure over the Wide Area Network (WAN) by linking two tunnel one primary and another secondary tunnel. Data path change during the call for packets transmission over non-failure tunnel [33]. A brief description about year wise development of reliability analysis techniques for VoIP are shown in Table 1 below.
Table 1. An Overview of VoIP Reliability Analysis Techniques.

| Author         | Year   | Techniques used for reliability analysis                                      |
|----------------|--------|--------------------------------------------------------------------------------|
| Hou et al      | 2002   | Markov analysis and Reliability Block Diagram [7].                             |
| Yoma et al     | 2005   | ordinary Gilbert model [16].                                                   |
| Sharma et al   | 2007   | SHARPE software for reliability analysis [2].                                  |
| Koutras et al  | 2007   | Semi-Markov modelling framework [27].                                          |
| Koutras et al  | 2009   | Continuous Time Markov Chain (CTMC) [26].                                      |
| Castanon et al | 2009   | Stochastic Petri Net [28].                                                     |
| Palade I       | 2010   | Reliability block diagram - IP RBD and Markov chains [17].                    |
| Guimaraes et al| 2010   | Stochastic Petri Net [8].                                                      |
| Hamdaqa et al  | 2011   | Lagrange Interpolation [23].                                                   |
| Pal et al      | 2011   | Linux in conjunction with a load balancer and ENUM [24].                      |
| Mahmood et al  | 2012   | OPNET Modeller 14.5 is used as network simulator [20].                         |
| Palade I       | 2012   | RAPTOR, Monte Carlo simulation [19].                                           |
| Toral-Cruz et al| 2013   | 2-state and 4-state Markov chains [15].                                       |
| Chhabra et al  | 2015   | Mean Opinion Score and R-Score in Wireless VoIP [37].                          |
| Bensalah et al | 2019   | Riverbed Modeller simulator [32].                                              |
| Murphy et al   | 2019   | RAPTOR [38].                                                                   |
| Dasari et al   | 2019   | NS-3 version 3.27,adhoc network topology [39].                                |
| Hu et al       | 2020   | MOS and QoE for packet [40].                                                   |
| Malekzadeh     | 2020   | The NS3 simulation tool implement the model [41].                              |
| Ganesan et al  | 2020   | Virtual Box, Mininet VM, POX Controller, Wireshark [42].                      |

3. Reliability of VoIP System
Reliability is probability of success. Reliability of a system or a device or a component is the probability of performance of its intended function for a given period of time with certain working condition. For example, a system having reliability of 0.9999 for one year has a continuously 99.99% functioning probability without any failure for the same year [10].

3.1. Reliability and Availability
Reliability effects availability, 99.99% reliability is not equal to 99.99% availability. Reliability measures ability of a system to function without failure, whereas availability is measurement of ability for providing service level continuously to customers. The reliability may be improved in VoIP by considering redundant hardware equipment within the networks including connections. The access gateways, signalling gateway and media server etc. can be made fault tolerant. Software can be upgraded to avoid the service loss [4]. Availability is the key metric for applications. Customers requires a high level of services. A small loss of service is acceptable but failure at system level is not tolerable [34].

3.2. Reliability and Availability of Data Networks
It is very difficult to measure the reliability and availability of data networks because of involvement of large number of equipment in a network including hardware and software. Therefore, it is impossible for data networks to catch the reliability bar defined by VoIP providers. As a measure for reliability, it requires calculation of Mean Time Between Failures (MTBF) [17]. In case of hardware and software repairable components of a network such as VoIP, if we assume the constant failure rate. then the reliability function become
\[ R(t) = e^{-\lambda t} = e^{-t/\text{MTBF}} \quad \text{where} \quad \lambda = \frac{1}{\text{MTBF}} \]  

\[ \text{Availability measure failures that comes out appears within the time interval (0, t). In case of irreparable system, the definition to measure A(t) is equivalent with R(t). Availability ‘A(t)’ that can be measured as below.} \]

\[ A(t) = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}} \]

3.3. Reliability Matrices

Communication networks like VoIP system consist of many electronic components and when a failure occurs unaffected components are not powered down. A very small increase in availability of system is very important [10, 26, 27]. Considering the important matrices to measure the reliability are mentioned as below.

3.3.1. Uptime

It is the time measurement of a system in hours for its operational state. For example, uptime of a VoIP system is 5000 hours. In case of reliability calculations, it is same as Mean Time Between Failures (MTBF).

3.3.2. Downtime

Average time of the equipment in hours when it is not in working mode. For example, downtime of VoIP equipment is 10 hours. In case of reliability calculations, it is same as MTTR.

3.3.3. Mean Time To Repair (MTTR)

It is the used by a person to repair the equipment for proper functioning. For calculating availability for any system MTBF and MTTR are required.

3.3.4. Mean Time Between Failures (MTBF)

MTBF is a parameter for measuring reliability and it is average time interval counted in hours between the failures.

3.3.5. Hardware MTBF

It is the mean time between hardware component failures. Hardware component redundancy avoids hardware equipment failures.

3.3.6. System MTBF

System MTBF is the mean time between system failures. The failure predicts the outage and may be restored by repairing. The MTBF of hardware equipment for a system can be increased by adding redundant components.

3.3.7. Failure Rate

Failure rate of hardware equipment is inverse of its MTBF and similarly, failure rate of a system is inverse of its MTBF. When Failure Rate becomes higher, MTBF will be smaller. Failure rate = \(1/\text{MTBF}\).

3.4. Reliability Issues in VoIP System

The VoIP networks are prone to cyber-attacks than the circuit switched networks. Voice quality and network issues need reliability assessment [30]. VoIP network faces many problems such as packet loss, jitter, latency, voice quality, software and hardware equipment. Different types of reliability issues exist in the present developments of VOIP technologies and are mentioned below.
3.4.1. **Software Reliability**
Software reliability has an important role for proper functioning of the system without failure because failure of any system component may increase other related problems. Security of VoIP system operation is possible with reliable software. The operation of the communication network and the availability of the files needed has an important role in reliability analysis [35].

3.4.2. **Link Failure**
There are several reasons for link failure for example, equipment failure, cable cut, power failure, switch or router failure, virus attack, packet lost from source to destination and Denial of Service (DoS) attack. Link failure can occur suddenly and may remain for a long time. Link can be re-established if the problem is caused by non-availability of suitable path because reliable routers can find another possible path. Link failure impacts the quality of speech in VoIP network [14].

3.4.3. **Packet Loss**
Packet loss in VoIP system is caused by non-availability of suitable bandwidth on the network system. Data packets travel through router in the network follow different paths from source to destination and some packets may have lost in between. Packet loss causes the degraded audio and video quality which is not acceptable in standard and business communications. Moreover, loss of few packets in VoIP communication is not a big problem but in case of a loss of data packet carrying confidential information passing through the network may raise the question on integrity of secret information [16].

3.4.4. **Network Availability and Outages**
Network systems availability is not possible all the time because of involvement of lots of components in between such as hardware, software and link. VoIP system failure in business systems may lead to a big loss of money because of communication failure. The service providers are required to find a suitable solution. Outage occur when one main system is down and reliability standards for VoIP are necessary such as PSTN standards [36].

3.4.5. **Quality of Service (QoS)**
Due to the involvement of different types of network applications in VoIP system quality of service is a big demand. The voice packets must reach from source to destination along with quality of transmission. Packet loss, jitter, latency and delay are the main issues which remain in VoIP network. Real time communication such as VoIP requires a low level of latency in network for the purpose of performance of high level of voice and video quality. QoS can influence the Quality of Experience (QoE) in VoIP communication. To evaluate the reliability of VoIP traffic QoE from the VoIP users is very critical to analyse [32].

3.4.6. **Network Design**
Network design is responsible for reliability of the VoIP system. If VoIP network is not designed properly than reliability of the system will be affected. Latency, packed loss and jitter are the key issues in network design. When VoIP is implemented over wireless networks, it becomes critical to design the network and issues such as reliability and QoS cannot be ignored. For the purpose of development of 5G network, network design is emerging as difficult area. The performance of network systems like VoIP communication systems require consideration in designing stable environment. Indices like reliability and availability may be important to measure the performance of a system [11].

3.4.7. **Power Requirements**
Power supply interruption creates the outages in VoIP network. The power required depends on specifications of the equipment. Sometime equipment consumes a very less power than the actual
supply. Power supply rating cannot be considered to be same as power consumption of network equipment. Most of the network equipment requires either normal AC or normal DC supply. VoIP phone gets power through Ethernet via unused wires. In case of analog phone and digital phone, power is supplied by PBX switch [36].

4. Conclusions
In the past year communication development of VoIP has taken place at a large extent with the reliability issues. It is tried to survey reliability techniques used by researchers with discussion on existing reliability issues. Further, an overview of reliability analysis techniques is presented in table format along with important reliability matrices to be considered in VoIP development. It is observed that future of VoIP depends on improving the quality of voice by solving the reliability issues. Whereas number of solutions has been deployed by the researchers but the attention should be given on solving Quality of Service (QoS) problems such as link failure, packet loss, delay and jitter during the VoIP data communication. Moreover, Reliability improvement for components involved in data communication should be given importance for betterment of voice quality in VoIP systems.

References
[1] Jalendry S and Verma S 2015 A detail review on voice over internet protocol (voip) Int. J Eng. Trends Technology 23(4) 161-166
[2] Sharma V S and Trivedi K S 2007 Quantifying software performance, reliability and security: An architecture-based approach Journal of Systems and Software 80(4) 493-509
[3] Sinaeepourfard A and Hussain H M 2011 Comparison of VoIP and PSTN services by statistical analysis IEEE Student Conference on Research and Development 459-461
[4] Raj R, Gagneja A and Singal R 2012 Voice over Internet Protocol–The Technology and Its Application International Journal of Scientific and Engineering Research 3(5) 1-6
[5] Pourghasem J, Karimi S and Edalatpanah S 2012 A Survey of Voice Over Internet Protocol (VOIP) Technology JICMSA 6(3-4) 53–62
[6] Raheja T and Munjal D 2015 A Comprehensive Survey on Voice over Internet Protocol (VoIP). IJARCET 4(4) 1552-1557
[7] Hou W and Okogbaa O G 2002 A simplified availability modeling tool for networks with 1: 1 redundant software-hardware systems IEEE Annual Reliability and Maintainability Symposium Proceedings (Cat. No. 02CH37318) 556-562
[8] Guimares A P, Maciel P R M and Matias R 2010 Dependability and performability modeling of voice and data networks IEEE Latin-American Conference on Communications 1-6
[9] Conway A E and Khasnabish B 2006 End-to-end network reliability modeling of enterprise VoIP services IEEE/IFIP Network Operations and Management Symposium 404-413
[10] Gorti A 2006 A fault tolerant VoIP implementation based on open standards IEEE Sixth European Dependable Computing Conference 35-38
[11] Al-Kuwaiti M, Kyriakopoulos N and Hussein S 2009 A comparative analysis of network dependability, fault-tolerance, reliability, security, and survivability IEEE Communications Surveys and Tutorials 11(2) 106-124
[12] Ali S R 2019 Reliability Analysis of VoIP System Next Generation and Advanced Network Reliability Analysis (Springer Cham ) 211-244
[13] Fiedler J, Kupka T, Magedanz T and Kleis M 2006 Reliable VoIP services using a peer-to-peer intranet Eighth IEEE International Symposium on Multimedia (ISM’06) 121-130
[14] Meeran M T, Annus P and Le Moullec Y 2016 The current state of voice over internet protocol in wireless mesh networks IEEE International Conference on Advances in Computing, Communications and Informatics 2567-2575
[15] Toral-Cruz H, Pathan A S K and Pacheco J C R 2013 Accurate modeling of VoIP traffic QoS parameters in current and future networks with multifractal and Markov models Mathematical and Computer Modelling 57(11-12) 2832-2845
[16] Yoma N B, Busso C and Soto I 2005 Packet-loss modelling in IP networks with state-duration constraints *IEE Proceedings-Communications* **152**(1) 1-5
[17] Palade I 2010 Reliability and availability engineering for VoIP communications systems *IEEE 8th International Conference on Communications* 309-312
[18] Jiang W and Schulzrinne H 2003 Assessment of voip service availability in the currentinternet *Proceedings of the 4th International Workshop on Passive and Active Network Measurement (PAM 2003)* 1-7
[19] Palade I 2012 A new approach in using RAPTOR to evaluate reliability and availability for VoIP systems *IEEE 9th International Conference on Communications* 217-220
[20] Mahmood M K, Al-Naima F M and Uzunoglu N K 2012 Design and simulation of a data transmission network for industrial control system subject to reliability improvement *IEEE International Conference on Future Communication Networks* 23-28
[21] Gierszal H, Sdongos E, Kiedrowski Ł, Korzeniowski, D Pluciński, K Brajer, Ł and Jackson J 2016 Reliability of SATCOM transmission for PPDR usage *IEEE 12th International Conference on Wireless and Mobile Computing, Networking and Communications* 1-8
[22] Gupta V and Dharmaraja S 2013 Reliability and performance modelling of VoIP system with multiple component failures *International Journal of Reliability and Safety* **7**(1) 58-74
[23] Hamdaqa M and Tahvildari L 2011 ReLACK: a reliable VoIP steganography approach *IEEE Fifth International Conference on Secure Software Integration and Reliability Improvement* 189-197
[24] Pal S, Gadde R and Latchman H A 2011 On the reliability of Voice over IP (VoIP) telephony *SPRING 9th International Conference on Computing Communications and Control Technologies* (Orlando, Florida, USA) 1-6
[25] Bai G, Long K, Wang W and Cheng S 1999 A new reliable signalling transport protocol RSTP for voice over IP *IEEE Fifth Asia-Pacific Conference on... and Fourth Optoelectronics and Communications Conference on Communications* (1) 263-266
[26] Koutras V P, Salagaras C P S and Platis A N 2009 Software rejuvenation for higher levels of VoIP availability and mean time to failure *IEEE Fourth International Conference on Dependability of Computer Systems* 99-106
[27] Koutras V P and Platis A N 2007 VoIP availability and service reliability through software rejuvenation policies *IEEE 2nd International Conference on Dependability of Computer Systems* 262-269
[28] Castanon G, Sarmiento A M, Ramirez-Velarde R and Aragón-Zavala A 2009 Software tool for network reliability and availability analysis *Wire Journal International* 74 1-13
[29] Daengsi T and Wuttidittachotti P 2013 VoIP quality measurement: enhanced E-model using bias factor *IEEE Global Communications Conference* 1329-1334
[30] Chu C H K, Pant H, Richman S H and Wu P 2006 Enterprise VoIP reliability *IEEE 12th International Telecommunications Network Strategy and Planning Symposium* 1-6
[31] Johnson C R, Kogan Y, Levy Y, Saheban F and Tarapore P 2004 VoIP reliability: a service provider's perspective *IEEE Communications Magazine* **42**(7) 48-54.
[32] Bensalah F, Bahnasse A, and El Hamzaoui M 2019 Quality of Service Performance Evaluation of Next-Generation Network *IEEE 2nd International Conference on Computer Applications and Information Security* 1-5
[33] Datta S, Ragula B and Balasubramaniam P 2015 U.S. Patent No. 8,995,252 *U.S. Patent and Trademark Office* (Washington, DC) 1-14
[34] Vargas E and Blue Prints S 2000 High availability fundamentals. Sun Blueprints series Part no. 806-6857-10 1-19
[35] Chen M J, Wen C C, Lin H C and Chu Y S 2016 ASIC design and implementation for VoIP intrusion prevention system *IEEE International Conference on Applied System Innovation* 1-4
[36] Rippon W J 2006 Threat assessment of IP based voice systems 1st IEEE Workshop on VoIP
Management and Security 19-28

[37] Chhabra A and Singh D 2015 Assessment of VoIP E-model over 802.11 wireless Mesh network  
IEEE International Conference on Advances in Computer Engineering and Applications 856-860

[38] Murphy K, Carter C, Grimes E and Malerich A 2019 RAPTOR 7.0 Tutorial Workbook 10-6

[39] Dasari V, Alexander D, Brown S, Brooks J, Panneton B and Su S 2019 Analysis of High fidelity ns-3 simulations to study real-time application performance in tactical wireless networks  
IEEE International Conference on Big Data 3955-3959

[40] Hu Z, Yan H, Yan T, Geng H and Liu G 2020 Evaluating QoE in VoIP networks with QoS mapping and machine learning algorithms  
Neurocomputing 386 63-83

[41] Malekzadeh M 2020 Combination of Access Categories and Frame Aggregation Schemes For Bandwidth Efficiency of VHT 802.11 AC  
Journal of Engineering Science and Technology 15(1) 617-635

[42] Ganesan N and Thangaraju B 2020 Pox Controller based Qos Evaluation for 5G Systems- 
Network Slicing  
IEEE 7th International Conference on Signal Processing and Integrated Networks 394-398