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Link Failure Detection in Multimedia Sensor Networks Using Multi-Tier Clustering Based VGG-CNN Classification Approach

S. Arockia Jayadhas
Faculty of Electronics, Sathyabama Institute of Science and Technology, Chennai, Tamil Nadu, India
dhasjohn85@gmail.com

S. Emalda Roslin
Department of ECE, Sathyabama Institute of Science and Technology, Chennai, Tamil Nadu, India
roemi_mich@yahoo.co.in

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Abstract – The transferring of huge multimedia data over the limited bandwidth environment has many challenges in real time. Wireless Multimedia Sensor Networks (WMSN) is a special type of wireless sensor networks which are used to overcome such bandwidth limitations in order to provide effective transferring of multimedia data. The malicious nodes in WMSN fail the links between the sensor nodes which degrades the efficiency of the entire network. Each node in WMSN may have its own signal transferring capability based on its energy level. If the energy level of the node degrades beyond the threshold level, that node becomes malicious node which is the main reason for the link failure between this node and its surrounding nodes. The data transfer is affected by the link failure nodes which degrades the performance of the entire system. Hence, the detection of link failure is important to improve the performance efficiency of the network system. This paper focuses the link failure detection system using deep learning approach. Hence, the detection of link failure is an important task to improve the performance of the network. This paper proposes an effective methodology for detecting the link failures of clusters in WMSN using deep learning architecture. The nodes in WMSN are grouped in to number of clusters and cluster head is determined using multi tier clustering approach, based on the energy levels and weighting metric approach. Then, the features are computed from each cluster and these features are classified using Visual Geometry Group (VGG) classification approach in order to detect the link failures of the clusters in WMSN. The performance of this developed methodology is analyzed with respect to Packet Delivery Ratio (PDR) and latency.

Index Terms – WMSN, Malicious, Link Failure, Deep Learning Architecture, Clusters, VGG.

1. INTRODUCTION

Wireless Multimedia Sensor Networks (WMSN) is the special type of Wireless Sensor Networks (WSN), which use multimedia sensor nodes or devices for capturing the sensing parameters and enable to transfer these sensed multimedia information to real world environment [1-3]. The contents in WMSN transfer are huge when compared with other wireless networks as the main challenge in WMSN environment. The limited bandwidth and power supply decreases the efficiency of the entire WMSN. This also reduced the Quality of Service (QoS) of the wireless networks. Many researchers from the past decades focused their research on developing the routing protocol for energy efficiency management and intruder detection of WMSN [4-7]. The energy efficient protocol provided an efficient energy aware methodology to minimize the energy levels during the multimedia data transfer or reception. The intruder detection system in WMSN detected the intruders or malicious sensor nodes to prevent data losses. The malicious sensor nodes create dummy multimedia data and transmit these data to all other sensor nodes in WMSN environment. This decreases the PDR and increases the transmission delay. Hence, the detection of malicious sensor nodes in network environment is essential to improve the QoS of the network model. These malicious nodes also consumed more energy of the sensor node and fail the sensor node activity [8-10]. This creates link failures between the sensor nodes which reduces the PDR rate. In order to improve the QoS of the entire network model, the link failure should be detected in WMSN. Hence, this paper develops an effective methodology to detect the link failure between sensor nodes.

The WMSN has two type of structure based on the sensor node connectivity as Flat type and hierarchical. In case of flat type network model, all sensor nodes are connected to sink node as shown in Figure 1 (a). In case of hierarchical type network model, all cluster head sensor nodes are connected to sink sensor node. Figure 1 (a) shows the flat WMSN architecture model and Figure 1 (b) shows the hierarchical WMSN architecture model.

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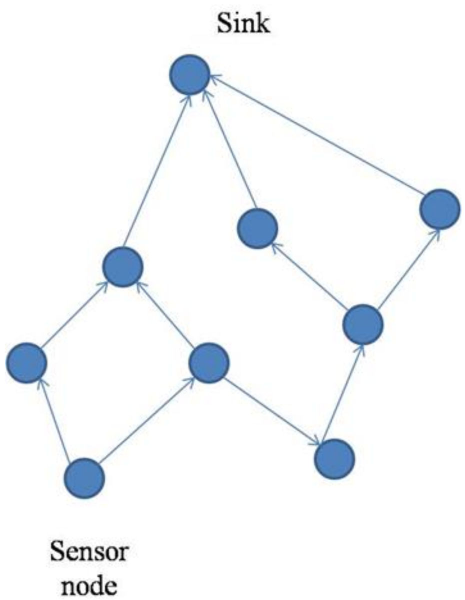
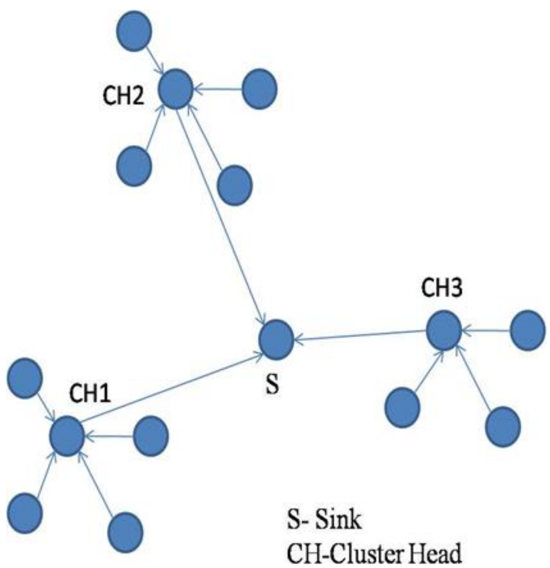


(a)



(b)

Figure 1 (a) Flat WMSN Architecture Model (b) Hierarchical WMSN Architecture Model

In Figure 1, all sensor nodes in WMSN architecture transfers the data to its corresponding CH and CH of each cluster send this information to the Sink node (S). Each node may have its own signal transferring capability based on its energy level. If the energy level of the node degrades beyond the threshold level, that node becomes malicious node which is the main reason for the link failure between this node and its surrounding nodes. The data transfer is affected by the link failure nodes which degrades the performance of the entire system. Hence, the detection of link failure is important to improve the performance efficiency of the network system. This paper focuses the link failure detection system using deep learning approach.

The main application of this paper is to implement these proposed methodologies in real time cloud system to transfer uninterrupted multimedia data. This motivates to bring this research work to detect the link failures in WMSN network environment. Though lot of methods available for link failure detection, its detection performance efficiency is low due to its complex architecture design. Hence, this paper develops an efficient methodology to detect the link failure in network using cluster based deep learning architecture.

The main contributions of this paper are stated below.

- CH is chosen using multi-tier cross layer designed routing method.
- The features are computed from each cluster and these features are classified using Visual Geometry Group (VGG) classification approach in order to detect the link failures of the clusters in WMSN.
- Performance of the link failure detection system is analyzed with respect to various parameters.

This paper is sectioned as, section 2 surveyed conventional schemes for identifying the link failures in WMSN, section 3 proposes an effective clustering based link failure detection methodology using VGG-CNN architecture, section 4 discusses simulation parameters obtained in this paper and section 5 concludes the paper.

2. LITERATURE SURVEY

Surabhi Patel et al. (2021) [11] proposed quadratic model for the detection and classification of link failures in wireless networks. The authors developed the proposed approach using their packet arrival rate between distant transmitter and receiver. The proposed system is simulated in NS2 and the results were compared with other networking non-linear protocols. The main limitation of this work is that its performance is degraded when more number of link failures occurred. Dsouza et al. (2021) [12] improved the QoS of the wireless network system through the development of detection system for reliable and stable nodes. These nodes in wireless networks were distinguished by the developed heuristic approach. The main limitation of this work is that it highly dependent on the routing protocols. Patel et al. (2020) [13] proposed regression based methodology to detect the link failures in the non-linear wireless networks. This proposed approach used various routing protocols to classify the link failures. This method consumed high energy when there are high numbers of link failures. Khudayer et al. (2020) [9] developed energy efficient routing mechanism for the

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detection and classification of link failures in wireless medium. The authors analyzed their developed protocol mechanism with respect to various energy based algorithms for link failure detection. This developed system achieved low throughput when there are high number of link failures as the main limitations of this work.

Chiwariro et al. (2020) [14] developed an energy aware routing mechanism for improving the quality of service in WMSN environment. The developed mechanism was tested on both simulation and real time environment in order to validate the effectiveness and robustness of the developed model. This method obtained 92.9% of PDR and 0.78 ms of delay in simulation environment and also this method obtained 91.8% of PDR and 0.96 ms of delay in real time environment in WMSN. The main limitation of this work is that the QoS of the developed architecture is low and not suitable for limited bandwidth constraints. Khudayer et al. (2020) [9] proposed an effective methodology for detecting the link failures in wireless communication medium. This method used route discovery protocol which incorporated energy efficient medium and source routing protocol for improving routing mechanism in an effective manner. The authors simulated their proposed methodology with respect to number of invalid or malicious nodes in order to verify the effectiveness of the proposed link failure detection system. The performance efficiency of this work was degraded if more number of malicious nodes present in the network architecture. Jain et al. (2019) [15] analyzed link failure in wireless networks using QoS aware link defined OLSR (LD-OLSR) routing protocol. The authors compared various simulation parameters with respect to link failures.

Genta et al. (2019) [16] used energy aware multipath routing scheme for improving the routing parameters in WMSN environment. This multipath routing scheme was tested on various real time test beds to prove the quality improvement efficiency. The authors obtained 90.1% of PDR and 89.1% of routing node failure detection rate. Gutiérrez et al. (2019) [17] proposed a supervised learning method which was used to monitor the real time environmental surrounding parameters for improving the un-interrupted services. The authors tested their proposed unsupervised methodology in artificial hydrocarbon networks. This proposed model consisted with two modules named as temperature measurement module and the sensor node failure detection module. The second module was activated when the first module lost their services in communication medium. Acharya et al. (2018) [18] used hierarchical multi path routing protocol to improve the quality of service in WMSN. The authors used clustering scheme to cluster the entire network to improve the energy rate in an effective manner. The cluster head in clustered networks consumed more energy during the entire service. Hence, this method developed scheme for reducing the energy consumption rate of the cluster head. This method obtained 87.9% of PDR and 0.89 ms of delay in simulation environment and also this method obtained 86.1% of PDR and 1.2 ms of delay in real time environment in WMSN. Bhanu et al. (2017) [19] created multiple software agents to transfer multimedia data to the uninterrupted multimedia networks. The authors formed multiple paths using the developed software agents to avoid the collision during the multimedia data transfer to other kind of wireless networks. The authors obtained 86.3% of PDR and 85.9% of routing node failure detection rate. Razaque et al. (2014) [20] developed energy efficient medium access control protocol for improving the level of security. The authors used energy aware routing mechanism to access the medium control plane of the wireless standard. The author tested their developed methodology on real time communication services in order to validate the effectiveness of this developed architecture.

From the literature survey section, the following limitations of the previous works are listed as,

- The network performance is degraded when more number of link failures occurred.
- Most of previous methods are highly dependent on the routing protocols
- Previous method consumed high energy when there are high numbers of link failures.
- Low throughput when there are high number of link failures as the main limitations of this work.

3. PROPOSED METHODOLOGY FOR LINK FAILURE DETECTION

This paper proposes an effective methodology for detecting the link failures of clusters in WMSN using deep learning architecture. The nodes in WMSN are grouped in to number of clusters based on the energy levels and weighting metric approach. Then, the features are computed from each cluster and these features are classified using Visual Geometry Group (VGG) classification approach in order to detect the link failures of the clusters in WMSN. Figure 2 shows the proposed flow of link failure detection in clusters of WMSN.

3.1. Clustering Approach

Clustering is the process of grouping the sensor nodes into certain number of groups based on their energy levels, weight factor and mobility index.

Initially, each sensor node is operated with 1000 J of energy. The energy consumption is occurred due to the continuous transmission and reception of data from one sensor node to another sensor node. At t=0, all the sensor nodes in environment are having same energy levels. At t=t1, the energy levels of the sensor nodes are different and the sensor nodes are groped based on their present energy levels of each

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sensor node (Razaque et al. 2014 [20]) using the constraints depicted in Table 1. In this paper, the sensor nodes are grouped into energy status E1 if their energy levels are varied from 900 J and 1000 J, the sensor nodes are grouped into energy status E2 if their energy levels are varied from 500 J and 900 J, the sensor nodes are grouped into energy status E3 if their energy levels are varied from 200 J and 500 J and the sensor nodes are grouped into energy status E4 if their energy levels are below 200 J, as illustrated in Table 1.

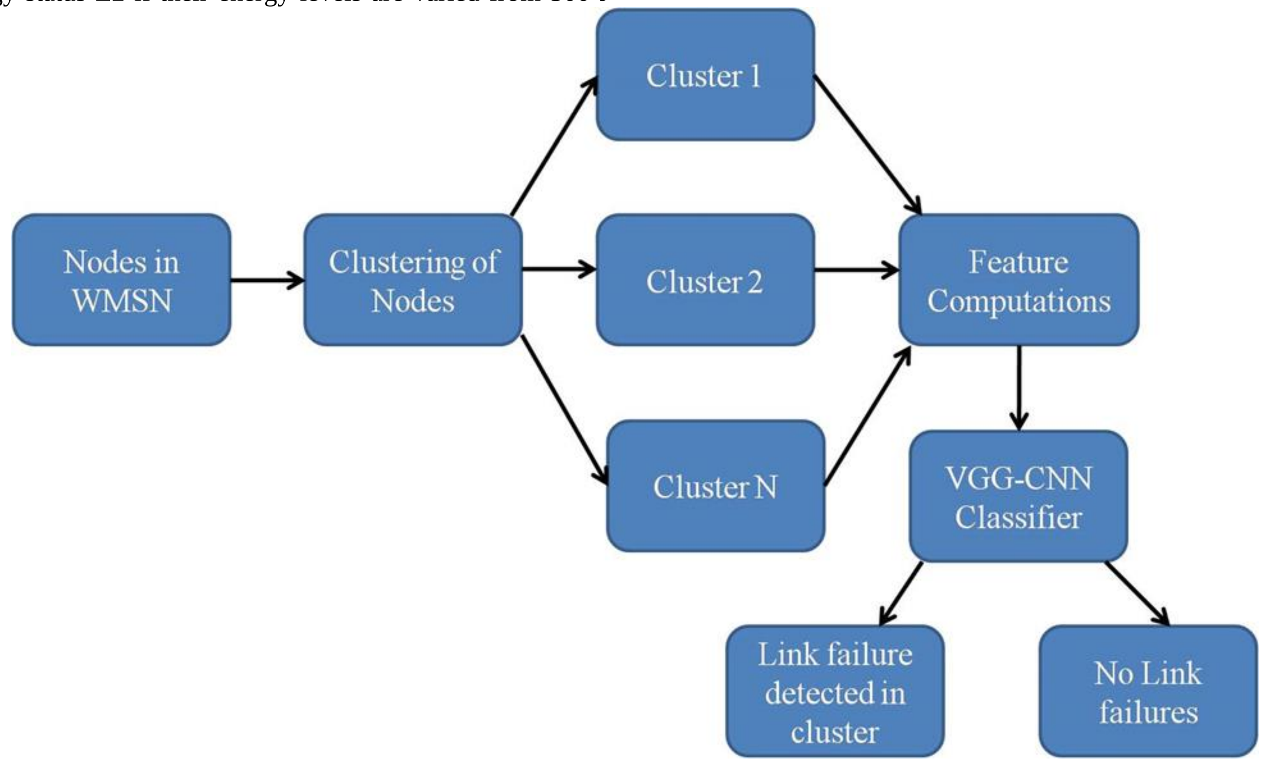

Figure 2 Proposed Flow of Link Failure Detection in Clusters of WMSN

Energy status	Energy levels
E1	900 J to 1000 J
E2	500 J to 900 J
E3	200 J to 500 J
E4	<200 J

Table 1 Clustering Based on Energy Levels of Sensor Nodes

The weight factor each sensor node is determined based on the computed energy status. If the energy status of sensor node is E1, the kappa factor (k) is set to 1, if the energy status of sensor node is E2, k is set to 0.5, if the energy status of sensor node is E3, k is set to 0.3 and if the energy status of sensor node is E4, k is set to 0.1.

The weighting factor of each sensor node is determined using the following equation (1).

$$w_i = \frac{\beta_i - \alpha_i}{k_i} \quad (1)$$

Whereas, β_i is the total number of received packets of sensor node i at t=t1 and α_i is the total number of transmitted packets of sensor node i at t=t1.

The mobility index of each sensor node is computed based on their velocity of sensor node with its corresponding weighting factor using the following equation (2).

$$m_i = \frac{v_i \times w_i}{v_i - w_i} \times 100\% \quad (2)$$

The clustering of sensor nodes is determined using the weighting factor and the mobility index of each sensor node as illustrated in the following equation (3).

$$Cluster = \begin{cases} C1; if \ \frac{w_i}{m_i} > 0 \\ C2; if \ \frac{w_i}{m_i} < 0 \\ C3; if \ \frac{w_i}{m_i} = 0 \end{cases} \quad (3)$$

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The cluster head can be determined using either single tier or multi-tier routing protocol as described in Han G et al. (2016) [21]. The routing and clustering efficiency is high in multi-tier routing than the single tier routing. Hence, multi-tier routing is used in this paper to find the cluster head. There are different types of multi-tier routing protocol available as priority based, hybrid routing method and cross layer designed routing. Among these multi-tier routing methods, the energy consumption is low in case of cross layer designed routing. Hence, the cluster head is determined using multi-tier cross layer designed routing method. The quality of link between two sensor nodes and the distance between them are the key metrics to determine the cluster head. The quality of the link and the distance between them are determined by measuring Signal to Noise Ratio (SNR) and Bit Error Rate (BER). Both SNR and BER are inversely proportional to each other, as SNR should be high while the BER should be as low as possible.

In this paper, 20 clusters are formed and the approximate CH detection time is 0.267 ms.

The cluster head of each cluster is determined that the sensor node with highest quality link in each cluster. The remaining sensor nodes in each cluster are connected with the cluster head. The cluster heads of each cluster is connected with each other in WMSN.

3.2. Feature Computations

Features represent the intrinsic behavior of sensor nodes in WMSN. It correlates the energy level variations of each sensor node in order to avoid the link failure due to energy level drop out. In this paper, the intrinsic feature of each cluster head is computed based on the energy levels of the cluster head and the remaining sensor nodes in corresponding cluster. The feature of the cluster head is determined using the following equation (4).

$$F(CH) = \begin{cases} +1\,; E_s \geq E_{CH} + t \\ -1; E_s \leq E_{CH} + t \\ 0; else \end{cases} \quad (4)$$

Whereas, E_{CH} is the energy level of the cluster head and E_s is the average energy level of the remaining sensor nodes in its corresponding cluster and t is the threshold level. In this paper, the threshold 't' is set to 0.5 after several iterations.

3.3. Classifications

The link failure between cluster heads can be determined using the classification approach. In this paper, VGG- CNN classification approach is used to determine the strength of the link between various clusters heads. VGG-CNN has the features of neural network to solve the classification problems. In this paper, 16 numbers of Convolutional Layers (CL) and five numbers of Pooling Layers (PL) and three numbers of Fully Connected Neural Networks (FCNN). These layers are grouped into six modules. Module 1 contains two CL and one PL, module 2 contains two CL and one PL. Module 3, 4 and 5 contains three CL and one PL. Module 6 contains three FCNN as illustrated in Figure 3. Each CL in module 1 contains 64 numbers of Convolution Filters (CF) and each CL in module 2 contains 128 numbers of CF. Each CL in module 3 contains 256 numbers of CF and each CL in module 4 and 5 contains 512 numbers of CF, as depicted in Table 2.

The extracted features are fed into the first CL. These features are convolved with the Convolutional kernel of filters in first CL. The response of this first CL is now passed to the CL2, which has the similar operation with CL1. The size of the response from the CL2 is now reduced using PL P1. In this paper, max pooling function is implemented with pooling layer. The final response from module 1 is passed to module 2 and so on. The response from module 5 is fed into FCNN layers of module 6. The first FCNN in module 6 is designed with 1024 numbers of neurons; the second FCNN in module 6 is designed with 1024 numbers of neurons and the third FCNN in module 6 is designed with 2 neuron as the final classification result. The first neuron in third FCNN represents class 1 and the second neuron in third FCNN represents class 2. The strength of the link between CH is determined based on class 1 and class 2, using the following equation (5).

$$Strength = \begin{cases} Good; if\ class\ 1\ and\ class\ 2\ are\ positive \\ Bad; else \end{cases} \quad (5)$$

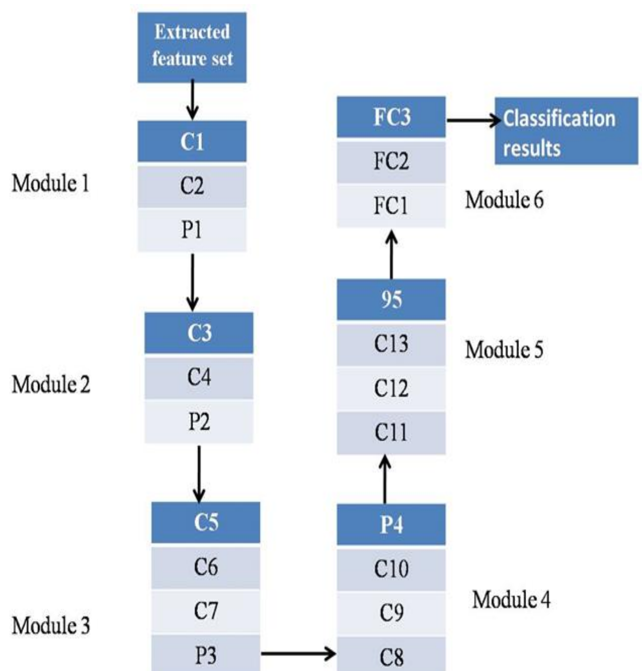

Figure 3 VGG-16 Architecture for the Classification of Links

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Layers specifications	Values
Number of modules	6
Number of CL in module 1	2
Number of CL in module 2	2
Number of CL in module 3	3
Number of CL in module 4	3
Number of CL in module 5	3
Number of FCNN in module 6	3
Number of CF in each CL of module 1	64
Number of CF in each CL of module 2	128
Number of CF in each CL of module 3	256
Number of CF in each CL of module 4	512
Number of CF in each CL of module 5	512

Table 2 Layer Specifications in VGG-16 Architecture

4. RESULTS AND DISCUSSIONS

The proposed link failure detection method is simulated using Network Simulator (NS2) simulation tool verson 2. This simulation tool is an open-source event-driven simulator which is exclusively designed for computer communication networks applications. This simulation software has the inbuilt simulation modules for the execution of various network protocols, routing algorithms and communication architectures. This NS2 simulation tool uses two languages for simulating the network environments such as C++ and Tcl. In this paper, Tcl language is used in NS2 simulation tool to simulate the proposed model. The simulation parameters which are used in simulation software is depicted in Table 3.

Simulation parameters	Initial values
Number of nodes	1000
Number of link failure nodes	80
Energy of the nodes	1200 J
Routing protocol	Link state routing protocol
Simulation area	1000 m * 1000 m as width and height

Table 3 Simulation Parameters in NS2

In this paper, the following parameters are used to analyze the proposed system.

$$Sensitivity\ (Se) = \frac{A}{A+D}*100\%$$

$$Specificity\ (Sp) = \frac{B}{B+C}*100\%$$

$$Accuracy\ (Acc) = \frac{A+B}{A+B+C+D} * 100\%$$

Whereas, A is the number of link failures correctly detected, B is the number of trust links correctly detected, C is the number of link failures falsely detected, D is the number of trust links falsely detected.

Table 4 shows the performance analysis of proposed method with respect to clustering approach in VGG. The proposed VGG method with clustering approach obtains 97.8% of Se, 98.1% of Sp and 98.4% of Acc, whereas the proposed VGG method without clustering approach obtains 86.6% of Se, 87.1% of Sp and 87.5% of Acc.

Parameters in %	VGG with Clustering	VGG without Clustering
Se	97.8	86.6
Sp	98.1	87.1
Acc	98.4	87.5

Table 4 Performance Analysis of Proposed Method with Respect to Clustering Approach in VGG

Further, the performance of the proposed link failure detection method is analyzed with respect to PDR and latency. Table 5 is the PDR analysis of proposed link failure detection method with respect to the impact of clustering approach in VGG classification model. The PDR decreases if the number of link failures is increasing high. The proposed link failure detection method obtains 99.1% of PDR if the detected link failure is 1. The proposed link failure detection method obtains 83.1% of PDR if the detected link failure is 10. Also, the VGG classification model is also analyzed without implementing clustering approach. This system obtains 96.5% of PDR if the detected link failure is 1 and the system obtains 75.1% of PDR if the number of detected link failure is 10.

Number of link failures	PDR (%)	
	VGG with clustering	VGG without clustering
1	99.1	96.5
2	98.2	93.1
3	96.6	92.9
4	95.1	90.4
5	94.2	88.6
6	93.1	85.1
7	90.1	82.9
8	87.5	79.1
9	85.9	77.3
10	83.1	75.1

Table 5 PDR Analysis of Proposed Link Failure Detection Method

From this analysis, the proposed link failure detection method with clustering approach provides superior performance in terms of PDR than the proposed link failure detection method without clustering approach.

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Table 6 is the throughput analysis of proposed link failure detection method with respect to clustering approach in VGG. The number of link failures reduces the throughput rate. The proposed method significantly achieves high throughput when compared with the VGG method without clustering approach.

Number of link failures	Throughput in b/s	
	VGG with clustering	VGG without clustering
1	98,275	92,187
2	95,185	90,276
3	92,186	87,754
4	89,462	80,286
5	85,835	72,617
6	81,757	65,289
7	78,386	55,827
8	75,947	48,816
9	73,927	46,370
10	70,716	41,276

Table 6 Throughput Analysis of Proposed Link Failure Detection Method

Table 7 is the detection rate analysis of proposed link failure detection method with respect to clustering approach in VGG. The number of failure nodes in network environment reduces the detection rate. The proposed method stated in this paper with clustering approach achieves significantly high detection rate when compared with the proposed method without clustering approach.

Number of link failure nodes	Detection rate (%)	
	VGG with clustering	VGG without clustering
20	98	95
40	93	86
60	86	80
80	81	71

Table 7 Detection Rate Analysis of Proposed Link Failure Detection Method

Table 8 is the latency analysis of proposed link failure detection method with and without clustering approach. The proposed link failure detection system with clustering approach consumed 0.1 ms if the number of detected link failure is 1. The proposed link failure detection system with clustering approach consumed 2.8 ms if the number of detected link failure is 10. Also, the VGG classification model is also analyzed without implementing clustering approach. The proposed link failure detection system without clustering approach consumed 0.35 ms if the number of detected link failure is 1. The proposed link failure detection system without clustering approach consumed 3.57ms if the number of detected link failure is 10.

Number of link failures	Latency (ms)	
	VGG with clustering	VGG without clustering
1	0.1	0.35
2	0.26	0.56
3	0.31	0.73
4	0.42	0.81
5	0.56	1.32
6	0.72	1.76
7	0.89	1.93
8	1.1	2.01
9	1.6	2.21
10	2.8	3.57

Table 8 Latency Analysis of Proposed Link Failure Detection Method

From this analysis, the proposed link failure detection method with clustering approach provides superior performance in terms of latency than the proposed link failure detection method without clustering approach.

Table 9 is the comparisons analysis of link failure detection methods with respect to various parameters. The proposed link failure detection scheme using cluster based CNN classification model provides superior results when compared with other conventional methods.

Methodologies	PDR (%)	Throughput (b/sec)	Se (%)	Sp (%)	Acc (%)	Detection rate (%)	Latency (ms)
Proposed work (in this paper)	94.2	70,716	97.8	98.1	98.4	81	0.56
Khudayer et al. (2020)	90.3	65,187	87.2	88.8	90.5	75	1.29
Gutiérrez et al. (2019)	87.9	62,461	85.1	86.5	87.7	76	1.32

Table 9 Comparisons of Link Failure Detection Methods with Respect to Various Parameters

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5. CONCLUSIONS

The link failure detection methodology using VGG-CNN classification is proposed in this paper in order to improve the performance of the WMSN. The sensor nodes in WMSN are grouped using the proposed clustering approach and the strength of the link between the clusters heads are detected using the proposed VGG-CNN classification methodology. The proposed link failure detection method obtains 99.1% of PDR if the detected link failure is 1. The proposed link failure detection method obtains 83.1% of PDR if the detected link failure is 10. Also, the VGG classification model is also analyzed without implementing clustering approach. The proposed link failure detection system with clustering approach consumed 0.1 ms if the number of detected link failure is 1. The proposed link failure detection system with clustering approach consumed 2.8 ms if the number of detected link failure is 10.

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Authors

S.Arockia Jayadhas graduated in Electronics & Telecommunication Engineering at Sathyabama University, Chennai in 2008. He secured Master of Engineering in Applied Electronics at Sathyabama University, Chennai in 2011. He is Pursuing Ph.D. in the field of Wireless Sensor Networks at Sathyabama Institute of Science and Technology, Chennai, India. He is in teaching profession for more than 12 years. He has presented number of papers in National and International Journals, Conference and Symposiums. His main area of interest includes Wireless sensor Networks and Internet of Things.

Dr. S. Emalda Roslin born on 7.8.1979, received her Bachelor's degree in Electronics and Communication Engineering from St. Josephs College of Engineering, Chennai in 2000. She received Master's degree in Applied Electronics from Sathyabama University, Chennai in 2004 and her Ph.D. in 2013 from Sathyabama University. She completed her doctoral research in "An Energy Efficient Topology Control Algorithm for Enhanced Network lifetime in Wireless Sensor Networks". She is currently working as a Professor in the Department of Electronics and Communication Engineering, Sathyabama Institute of Science and Technology, Chennai and she is having 19 years of teaching experience. She has published more than 50 research papers in various International/National Conferences and International / National Journals indexed in Web of Science/ Scopus/other databases. She is guiding around seven research scholars. Her major areas of interest are wireless multimedia networks, wireless mesh networks and image processing. She is also an editorial board member for various journals.

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