Energy efficient wireless sensor network with efficient data handling for real time landslide monitoring system using fuzzy data mining technique

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Abstract: Wireless sensor network (WSN) is one of the emerging areas which are extensively being used for development of real time monitoring systems. Landslides are the major cause of loss of life, human settlements, agriculture, forestland, and lead to damage of communication routes. In this paper, we propose new landslide monitoring system with maximising the life time of sensor nodes by avoiding link failure in routing protocol. The cluster-based routing protocol with the sensor nodes is capable of data acquisition, data storage, data processing, and wireless data transmission. Then, collected data's are aggregated using fuzzy data mining technique which maximise lifetime of all sensor nodes in the network area. The proposed approach is implemented and results are obtained through NS-2 simulation shows that the proposed algorithm performs better than other landslide monitoring systems in terms of network life time, sensor node life time, data transmission and energy consumption

Keywords: rain gauge; moisture sensor; pore pressure sensor; clustering; fuzzy data mining; network simulator; NS-2.

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1 Introduction

In recent years, wireless sensor network (WSN) has drawn many research works predominantly due to it is plenty of applications in various fields (Prayati, 2012; Hu et al., 2014; Ramesh, 2014). WSN refers to a group of spatially dispersed and dedicated sensors for monitoring and recording the physical conditions of an environment and organising the collected data at a central location through wireless links (Mohanty and Kabat, 2016; Furquim et al., 2015). The physical conditions may include pressure, temperature, soil moisture, etc. (Ma et al., 2014; Nguyen et al., 2015; Abdelgawad and Bayoumi, 2011; Jelicic et al., 2013; Davis et al., 2012). Each sensor node in sensor network is equipped with a radio transceiver, a microcontroller, an interfacing electronic circuit and an energy source, usually a battery (Guo et al., 2014). The sensor nodes are typically small and equipped with a low-powered battery (Arifuzzaman et al., 2013). Unlike other wireless networks, it is generally impractical to charge or replace the exhausted battery (Vamsi et al., 2014). Hence, the application of WSN in the area of interest for an event demands optimum utilisation of network resources so as to increase the lifespan of the sensor nodes. Hence enhancing the lifespan of the WSN nodes can, in turn, enhance the overall lifespan of the whole network increasing its reliability and usefulness in given environment. Various applications of WSN include environmental monitoring (Zhou et al., 2012; Mohanty and Kabat, 2016; Furquim et al., 2015), health monitoring (Bhuiyan et al., 2015), military tracking (Luo et al., 2012), animal tracking (Tsai et al., 2011), etc.

Environmental disasters are largely unpredictable and occur within very short spans of time. Forewarning of environmental disasters is more challenging than other applications due to the fact that they occur within a very short span. Therefore, technology has to be developed to capture relevant signals in a very short span of time (Cotuk et al., 2014). The forewarning of an environmental risk can be done if and only if the relevant data is available within very short time spans captured with high time resolution, for processing and transmitting it to the analysis station. Wireless sensors are one of the cutting-edge technologies that can respond to such a rapid change of data for real-time monitoring (Malatras et al., 2008).

In our research paper, we are concerned with the application of WSN for detecting and mitigating landslides (Ramesh, 2014; Ramesh and Rangan, 2014; Dardari, 2016) by paying attention towards energy minimisation, optimum overhead utilisation and reliability by employing multipath data transmission securing the given network from inside attacks. Landslide (landslip) is the short lived and suddenly occurring movement of ground that has catastrophic effects all around the world. Landslide is one of the most aggressive natural disasters that cause loss of lives and billions of dollars damages annually worldwide. They pose a threat to the safety of human lives, the environment, resources and property (Dardari, 2016) and the main classification criteria of landslides:

1 depends on movements like falls, topples, slides spreads and flows movements (Alkhasawneh et al., 2014; Colangelo and Guariglia, 2011; Intrieri et al., 2012; Uhlemann et al., 2016). Falls movement are detached from steep slope/cliff along surfaces with little or no shear displacement (e.g., joints/fissures) and descend mostly through the air by free fall, bouncing or rolling. Topples is the movements of rock, debris or earth masses by forward rotation about a pivot point. Slumps occurs when masses slide outwards and downwards on one or more concave-upward failure surfaces that impart a backwards tilt to the slipping mass, which sinks at the rear and heaves at the toe. Spreads involves the fracturing and lateral extension of coherent rock or soil masses due to plastic flow or liquefaction of subjacent material. Flows slow to rapid movements of saturated or dry materials which advance by flowing like a viscous fluid, usually following an initial sliding movement.

2 Type of material involved in movement like rock, debris and earth based material (Alkhasawneh et al., 2014; Colangelo and Guariglia, 2011; Intrieri et al., 2012; Uhlemann et al., 2016), landslide occurs when several of these factors individually or due to combination of factors such as gravity heavy, prolonged rainfall, earthquakes, forest fires, volcanoes, human activities and negligence (deforestation, deep excavation/mining, inappropriate drainage system). Landslide susceptibility is defined as the propensity of an area to generate landslides (Ramesh and Rangan, 2014). Assuming that landslide will occur in the future because of the same conditions that produced them in the past, susceptibility assessments can be used to predict the geographical location of future landslides.

Our contributions in this paper, we use multiple sensors to detect and predict any occurrence of landslides in the given location. During a positive prediction of landslides, all the natives in the location are also provided with a warning alert for immediate evacuation and rescue operations Ramesh and Rangan (2014).

The remainder of the paper is organised as follows. Sections 2 presents the recent works related to our contribution in this paper. The problem formation and solution with the system model is describes in Section 3. The proposed efficient landslide monitoring system (LMS) with mathematical formulation is present in Section 4. The performance of proposed protocol is analysed in Section 5. Finally, the paper concludes in Section 6.

2 Related works

In this section, the related works are discussed by three different cases such as:

1 WSNs for environment monitoring system

2 energy efficient routing protocol for WSNs

3 efficient data handling using data mining techniques.

2.1 WSNs for environment monitoring system

Ramesh and Vasudevan (2011) have presented deep earth probes (DEPs) based WSNs that used deployed to monitor an active landslide in the Western Ghats mountain range of South India. There have been a few earlier landslide monitoring WSNs using accelerometers in Emilia Romagna Apennines, Italy; global navigation satellite system (GNSS) sensors to monitor the Hornbergl landslide, Austria; and vibrating wire stress sensors to monitor a slope in China.

Turjman et al. (2015) have proposed powerful and cost-efficient solution for unattended outdoor environment monitoring (OEM) applications. These applications impose certain challenges on WSN deployment, including 3-dimensional (3-D) settings, harsh operational conditions, and limited energy resources.

Chen et al. (2013) have proposed an approach upon WSN for early warning on geohazards. Setup of sensors of the WSN is a priory issue. Various types of sensors may apply, e.g., interior displacement sensors, apparent displacement sensors, solid settle sensors, rainfall sensors, and water pressure sensors. Information collected by these sensors is first transferred to the base station via wireless multi hop transmission then the monitoring centre via wireless wide area network. The field monitoring level is responsible for data transmission and data reliability test for the WSN. The remote networks transfer field information to the monitoring centre. The monitoring centre performs data analysis and visualisation to support geohazard monitoring and management.

Bae et al. (2013) have proposed bridge health monitoring system. WSN signal obstruction from various bridge components, including girders, bracings and connectors, can affect the performance and reliability of wireless communication. Although the placement of sensor nodes is essential for forming a mesh or ad-hoc network, there are no quantitative approaches related to the optimal separation distance of each node and the corresponding signal quality.

Wu et al. (2016) have proposed framework with dedicated combination of data prediction, compression, and recovery to simultaneously achieve accuracy and efficiency of the data processing in clustered WSNs. It is reducing the communication cost while guaranteeing the data processing and data prediction accuracy. The data prediction is achieved by implementing the least mean square (LMS) dual prediction algorithm with optimal step size by minimising the mean-square derivation (MSD), in a way that the cluster heads (CHs) can obtain a good approximation of the real data from the sensor nodes.

Wang et al. (2011) have provided the analytical results of the path loss of the four types of channels. Based on the path loss analysis, the transmission range of each channel is derived, which completely depends on the environmental conditions. Then, they provide the critical density for the WSNs under the impact of sandstorms. Accordingly, they demonstrate that when sensors are buried in shallow depth, the critical density of the single medium communication scheme, which only uses terrestrial air channels (Zheng et al., 2005).

Goh et al. (2014) have presented hetero-core spliced optical fibre surface Plasmon resonance sensor system for soil gravity water monitoring in environments. The system simultaneously provides data communications and sensing functions over the same optical fibre line. The sensor is covered with tantalum pent oxide, which allows data transmission distance to be extended with a wavelength of 1,310 nm for wide-area monitoring. Sensor system can gather remotely observed environmental data from monitoring points and deliver them to users on a real-time basis.

2.2 Energy efficient routing protocol for WSNs

Lin et al. (2015) have proposed clustering protocol called fan shaped clustering (FSC) to partition a large-scale network into fan-shaped clusters. The different energy saving methods is used, such as efficient CH and relay selection, locality of re-clustering, simple but robust routing and hotspot solution.

Ke et al. (2016) have proposed energy aware hierarchical cluster-based (NEAHC) routing protocol with two goals: minimising the total energy consumption and ensuring fairness of energy consumption between nodes. Here the relay node choosing problem as a nonlinear programs problem and use the property of convex function to find the optimal solution.

Shahraki et al. (2011) have proposed routing protocol through intra-clustering. Most hierarchical protocols use direct intra-cluster routing, so that all the cluster member nodes forward their data to the CH node directly. Considered parameters are cluster lifetime and end to end delay between cluster member nodes and CH node. Also, rules related to queue theory have been used to determine end to end delay.

Sun et al. (2011) have presented an energy efficient clustering routing protocol based on weight (ECRPW) to prolong the lifetime of networks. ECRPW takes into consideration the nodes' residual energy during the election process of CHs. The constraint of distance threshold is used to optimise cluster scheme.

Lin and Wang (2016) have proposed routing protocol for WSNs called game theory based energy efficient clustering routing protocol (GEEC). GEEC, which belongs to a kind of clustering routing protocols, adopts evolutionary game theory mechanism to achieve energy exhaust equilibrium as well as lifetime extension at the same time.

Turgut and Hafif (2015) have proposed distributed clustering routing protocol (NODIC), which guarantees to elect the best candidate as CH without any iteration cost. The most common CH election parameters, including the energy and the location of the nodes, is performed under the same circumstances (i.e., using a single cluster).

2.3 Data mining techniques for efficient data handling

Srinivas et al. (2012) have proposed the single layer feed-forward neural network with the back-propagation algorithm is chosen as one of the well suited networks after comparing the results. Initially, certain synthetic data sets of all three-layer curves have been taken for training the network, and the network is validated by the field datasets collected from Tuticorin Coastal Region (787030”E and 848045”N), Tamil Nadu, India. With proper training of back propagation networks, it tends to give the resistivity and thickness of the subsurface layer model of the field resistivity data concerning the synthetic data trained earlier in the appropriate network.

Pwasong and Sathasivam (2016) have combined quadratic regression model (QRM) and a cascade forward back propagation neural network (CFBN) to form a hybrid model called the hybrid quadratic regression method and cascade forward back propagation neural (QRM-CFBN) network method. The hybrid method was tested on a daily time series data obtained from the UCI repository data link and the data set was collected from a combined cycle power plant. The joint integration was made possible by the Bayesian model averaging technique, which was used to obtain a combined forecast from the two separate methods.

3 Problem identification and system model

In this section, we first discuss the problems in Ramesh and Rangan (2014) and then provide the problem solution with the system model.

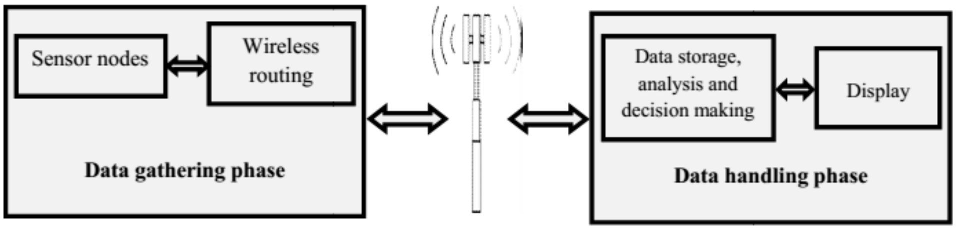
3.1 Problem identification and solution

Ramesh and Rangan (2014) have proposed WSN network with heterogeneous nodes for landslide detection employing data reduction and energy minimisation. Four different types of sensors were used to measure rainfall, moisture, pore pressure, and movement, all of which were in continuous operation for more than two years in the equatorial forests of Kerala, India. Predicted landslide and was intimated to the people dwelling/media/governing body in the given region. Prevented loss of human life, investigate some techniques to dynamically throttle the rates of sensor sampling and transmission, so as to significantly reduce the energy and increase the battery lifetime, without impacting the effectiveness of landslide monitoring and detection, and high reliability and effectiveness. The research was not focused more on:

- evaluating the magnitude of landslides from the data’s sensed using the sensor nodes
- the monitoring, analysis and broadcasting of magnitude of landslip for more reliable and effective evacuation
- the research does not deal with link failure (i.e., lifespan or death of the sensor nodes)
- they also did not deal with security treats involved when a node is hijacked to prevent the false information (notification which can mislead the local people and lead to chaos and complete confusion).

In our proposed network we employ multiple sensors connected to the sensor node. Using clustering (Lin et al., 2015; Ke et al., 2016; Shahraki et al., 2011; Sun et al., 2011; Lin and Wang, 2016; Turgut and Hafif, 2015) the sensor nodes is capable of data acquisition, data storage, data processing, and wireless data transmission. The sensed data are evaluated using fuzzy, at the main sensor node and is sent to the base station. Fuzzy evaluation at each sensor node is evaluated during sleep mode and only if the fuzzy output is ‘true’, the aggregated data is compressed and sent to the base station during an active period (Arifuzzaman et al., 2013). For each main sensor node, one queue is maintained at the base station. Hence, the chances of missing or collision of data at the base station is negligible. At base station carried out the process such as expert evaluation, data analysis (data mining), expert decision, warning (SMS) and alerting the rescue team (and other emergency contacts as listed by the designer). Each node is well aware of its GPS location, and hence, under the event of the landslide, the displacement of any location for post-disaster rescue can be evaluated. In the bad weather, the data is sensed and transmitted more frequently to ensure that the system can track the site’s status very well. In the normal condition, the data rate is reduced to save the power (Arifuzzaman et al., 2013). Under link failure due to dead main sensor node conditions or internal attack, backup path Mohanty and Kabat (2016) for data transmission is evaluated so that no data is missed out. Even under the hijack of sensor nodes (internal attack), path reliability is evaluated for each sensor nodes at the base station to eliminate false updates. Hence, the occurrence of DoS (Gill et al., 2012) and black hole attack (Motamedi and Yazdani, 2015) which can eventually drain the energy of the overall network can be tackled very easily.

Figure 1 Overview of proposed system model



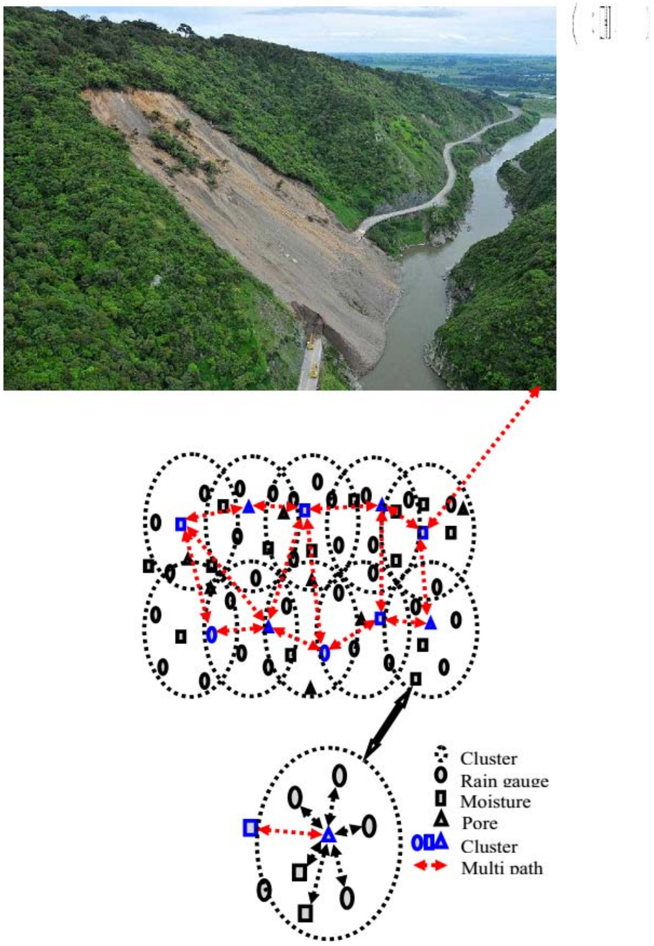
3.2 System model

The proposed energy efficient LMS model consists of two phases such as:

1 data gathering phase

2 data handling phase, the overview of proposed system is shown in Figure 1.

Figure 2 Detailed structure of our proposed procedure in data gathering phase (see online version for colours)



The data gathering phase is responsible for data collecting and data transmission for the WSN. The sensor nodes are responsible for collecting environmental information, i.e., rainfall, moisture, pore pressure. The collected information's are transferred from senor nodes to base station by proposed energy efficient routing protocol based on clustering techniques. Then the base station transfers all collected information in to data handling phase to analyse the possibility of landslide in the given area. The fuzzy based data mining technique is used to handle the different sensor values such as rainfall in terms of millimetre (mm) or inch, moisture sensor in terms percentage and pore pressure in terms of kilopascal (kPa). The predicted output is transfer to display panel of data handling phase.

In two phase systems, our contribution is in data gathering phase by achieving multipath routing in terms of enhanced cluster based technique. It is consist of two steps such as cluster formation and CH selection process. All sensor nodes in cluster are connected with in the CH of that cluster. Only CH sensor nodes are connected each other, and base station is connected nearby CH sensor node and the detailed structure is shown in Figure 2.

4 Proposed two phase LMS

4.1 Data gathering phase

In data gathering phase to collect landslide factors, rainfall, moisture and pore pressure using different sensor nodes such as rain gauge, moisture sensor and pore pressure gauge. Then the collected information's are transferred from sensor nodes to base station via proposed routing protocol. The proposed energy efficient routing protocols are implemented from clustering techniques. The cluster formation is depending on two steps, cluster formation and CH selection process. Further energy efficiency is achieved by data evaluating phase in which the fuzzy logic is used to evaluate the peak values and it is selectively transfer to base station.

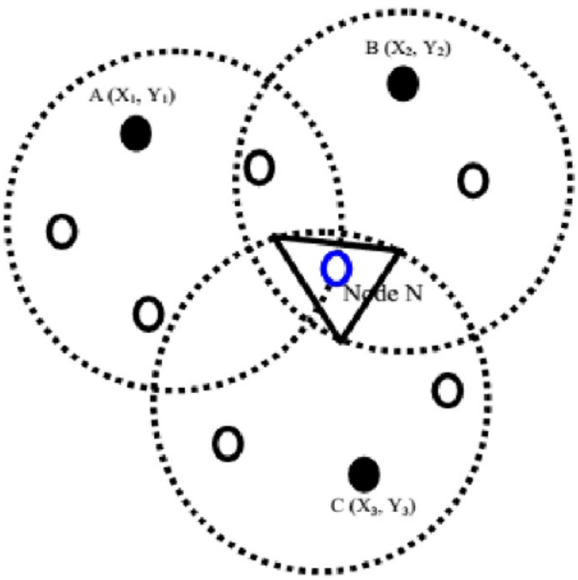
4.1.1 Cluster formation

The base station divides the network area into different number of cluster format based on localisation technique. The geographical locations of sensors, assigns ID to clusters and sensor nodes are required to calculate the sensor node in present in the cluster or not. The sensor information's are represented by location of that particular sensor for both wired and wireless applications. In localisation based clustering technique, location updating process is the critical factor and the sensor nodes are localised at the cluster formation phase and whenever a node moves out of a cluster to join a new cluster. Although moving sensors inside a cluster change their location their initial location in the cluster can still allow the applications to predict the location of the event of interest. This localisation approach uses sensing range to communicate with nodes, where a pair of nodes communicates each other only when their sensing circles intersect each other. One or more neighbouring localised nodes in the network are used to localise the un-localised sensor nodes. Sensor node moves and broadcasts it is current position. Consider an un-localised node N in Figure 3 that is within the sensing range of localised special node receives the node position and assumes that special node exists at that position. Un-localised node $N(X_n, Y_n)$ receives the location information of considered neighboured localised nodes with the location of $A(X_1, Y_1)$, $B(X_1, Y_1)$ and $C(X_1, Y_1)$. Un-localised node N computes it is location by connecting intersected position of sensing circles and it is represented as follows:

$$X_n = \frac{1}{3}\sum_{i=1}^{3} X_i \quad (1)$$

$$Y_n = \frac{1}{3}\sum_{i=1}^{3} Y_i \quad (2)$$

Figure 3 Localisation of un-localised sensor node n (see online version for colours)



4.1.2 CH selection

The CH is selected from energy and trust level of each sensor nodes in the cluster which improves the security and energy efficiency.

4.1.2.1 Energy model

The transmitter and receiver dissipate energy to run the radio electronics and the power amplifier. The energy consumption of the node depends on the amount of the data and distance to be sent. The energy consumption of a node is proportional to square of distance (D^2) when the propagation distance (D) less than the threshold distance (D_0), otherwise it is proportional to (D^2). The total energy consumption of each node in the network for transmits and receives the n bit data packet as follows:

$$E_{total} = E_t(n, d) + E_r(n) \quad (3)$$

where $E_t(n, d)$ and $E_r(n)$ are energy consumption of transmitting and receiving node.

$$E_t(n, d) = \begin{cases} n \times E_{elec} + n \times \varepsilon_{fs} \times D^2; & if\ D < D_0 \\ n \times E_{elec} + n \times \varepsilon_{mp} \times D^4; & if\ D \geq D_0 \end{cases} \quad (4)$$

$$E_r(n) = n \times E_{elec} \quad (5)$$

where E_{elec} the energy is dissipated per bit to run the transmitter or receiver circuit, amplification energy for free space model (ε_{fs}) and for multi-path model (ε_{mp}) depends on the transmitter amplifier model and D_0 is the threshold transmission distance. The total current energy (E_{CH_x}) of CH_x; $1 \leq x \leq m$ is selected from the normal sensor nodes in iteration. The total current energy of all the selected CHs:

$$E_{total} = \sum_{x=1}^{m} E_{CH_x} \quad (6)$$

4.1.2.2 Trust inference model

Consider the sensor nodes N_i and N_j with the minimum and maximum trust threshold values are $T_{\min}$ and $T_{\max}$. The trust value reveals the degree of trust or distrust that the node N_i holds on N_j and it is estimated as follows:

$$T(i, j) = \tanh\left(\sum_{z=1}^{n} \alpha_z \beta_Z\right) \quad (7)$$

where z is interaction between the nodes, n is the number of interaction between the two nodes, β_z is the weight of interaction number z, $\alpha_z = +1$ if the interaction z is positive and $\alpha_z = -1$, if the interaction z is negative. The relation among N_i and N_j is said to be totally trusted (T_{tot}) if and only if $T(i, j) \in [T_{\max}, 1]$ and $T(j, i) \in [T_{\max}, 1]$. When the nodes are deployed in the network, it broadcasts the hello message to its neighbouring nodes. The format of hello message is shown in Table 1.

Table 1 Hello message format

Hello message				
Node ID	Energy value E_{total}	Trust value $T(i, j)$	Number of hop (H)	CH ID

Based on the hello message each node identifies itself and also maintains the neighbours list. Once the selected node is declared as CH, it updates its identity in the CH field of its hello messages and sets the H field of these messages as 'zero'. All neighbouring nodes which contain the trusted relations with CH join the cluster. HELLO message contains the identity of CH in the CH field and H field of these messages as 'one'. If there exist some nodes without joining the cluster and it holds the trust relation with at least once cluster, then it joins the cluster with maximum trust value.

4.2 Energy efficient data handling phase

The small sensor nodes are using low power battery which not easy to replace the power battery in the limited periods. The energy consumption of sensor nodes is defining the life time of sensors as well as whole sensor networks. The energy attributes are considering as critical factor in multi path routing protocol other than delay, data loss and delivery ratios. Most of the energy wastages are occurred only in idle sensing stage. The problem is reduced by modify the design to make energy efficient by the condition, sensor nodes are do not wake up all the time rather prefer energy preservation by going to sleep mode (Arifuzzaman et al., 2013). The energy consumption of the sensor nodes is depending on the different stages such as energy consumption due to transmitting, receiving, overhearing and idle stages. Energy consumption of sensor nodes are very less in the sleep mode compare to the active or idle mode. The total simulation time (Sim_t) of routing protocol process is as follows:

$$Sim_t = Tx_t + Rx_t + OH_t + Idle_t + Sleep_t + Tra_{SA_t} \tag{8}$$

where Tx_t, Rx_t, OH_t, $Idle_t$, $Sleep_t$ and Tra_{SA_t} is time spent for sensor nodes performed data transmitting, receiving, overhearing, idle, sleep, and transmission from sleep to idle active mode. The energy consumption of total simulation time (Sim_t) is representing as follows:

$$\begin{aligned} E_{sim_t} = {} & Tx_t \times E_t(n, d) + Rx_t \times E_r(n) + OH_t \\ & \times E_{OH}(n) + Idle_t \times E_{idle}(n) + Sleep_t \\ & \times E_{sleep}(n) + Trans_t + E_{trans}(n) \end{aligned} \tag{9}$$

Figure 4 Fuzzy inference model with landslide crisp data

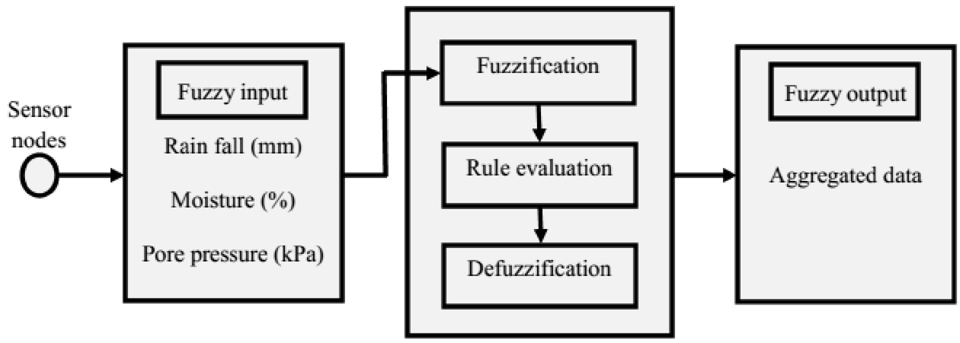
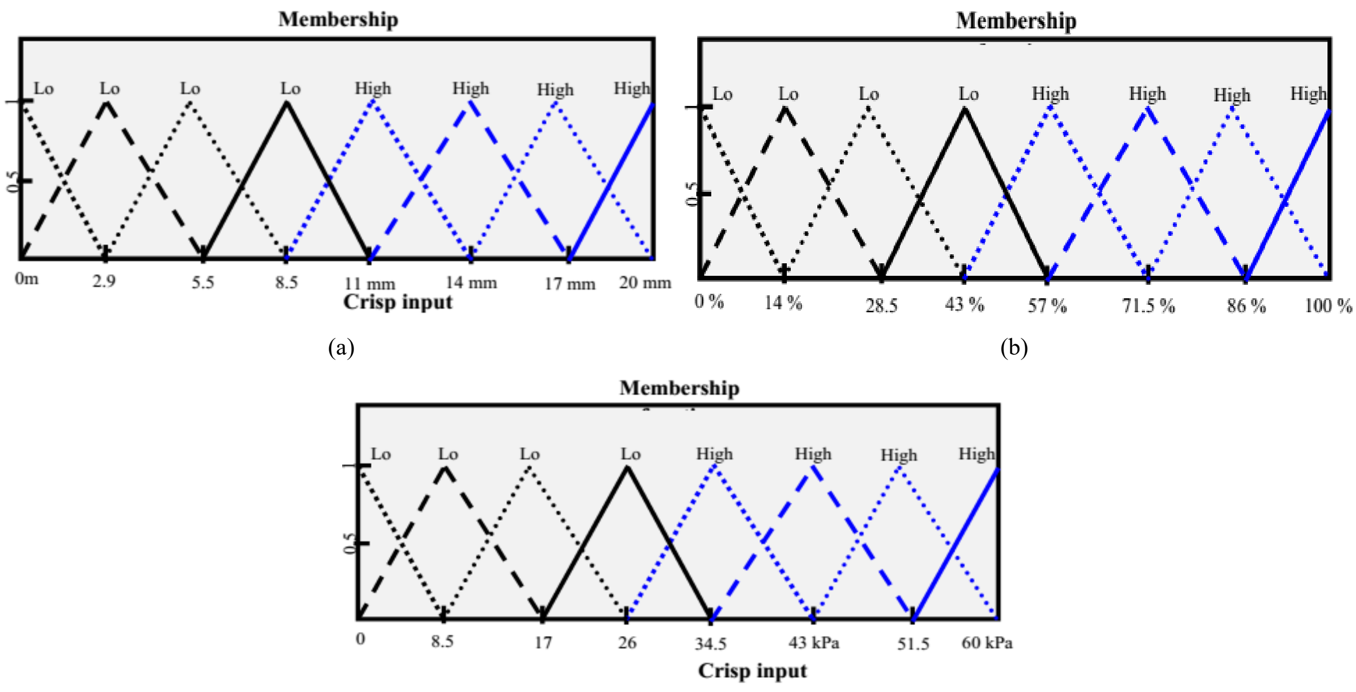


Figure 5 Membership function for (a) rainfall values, (b) moisture values and (c) pore pressure values (see online version for colours)



(c)

Table 2 All possible data combinations

No	*Rainfall*	*Moisture*	*Pore pressure*	*Aggregated data*	*No*	*Rainfall*	*Moisture*	*Pore pressure*	*Aggregated data*
1	Low1	Low1	Low1	False	65	Low2	Low1	Low1	False
2	Low1	Low1	Low2	False	66	Low2	Low1	Low2	False
3	Low1	Low1	Low3	False	67	Low2	Low1	Low3	False
4	Low1	Low1	Low4	False	68	Low2	Low1	Low4	False
5	Low1	Low1	High1	False	69	Low2	Low1	High1	False
6	Low1	Low1	High2	False	70	Low2	Low1	High2	False
7	Low1	Low1	High3	False	71	Low2	Low1	High3	False
8	Low1	Low1	High4	False	72	Low2	Low1	High4	False
9	Low1	Low2	Low1	False	73	Low2	Low2	Low1	False
10	Low1	Low2	Low2	False	74	Low2	Low2	Low2	False
11	Low1	Low2	Low3	False	75	Low2	Low2	Low3	False
12	Low1	Low2	Low4	False	76	Low2	Low2	Low4	False
13	Low1	Low2	High1	False	77	Low2	Low2	High1	False
14	Low1	Low2	High2	False	78	Low2	Low2	High2	False
15	Low1	Low2	High3	False	79	Low2	Low2	High3	False
16	Low1	Low2	High4	False	80	Low2	Low2	High4	False
⋮					⋮				
57	Low1	High4	Low1	False	505	High4	High4	Low1	False
58	Low1	High4	Low2	False	506	High4	High4	Low2	False
59	Low1	High4	Low3	False	507	High4	High4	Low3	False
60	Low1	High4	Low4	False	508	High4	High4	Low4	False
61	Low1	High4	High1	False	509	High4	High4	High1	False
62	Low1	High4	High2	False	510	High4	High4	High2	False
63	Low1	High4	High3	False	511	High4	High4	High3	False
64	Low1	High4	High4	True	512	High4	High4	High4	False

Table 3 Possible aggregated data transferred to base station

Rainfall	*Moisture*	*Pore pressure*	*Aggregated data*
High4	Low1	Low1	True
High3	Low2	Low2	True
High2	Low3	Low3	True
High1	Low4	Low4	True
Low4	High1	High1	True
Low3	High2	High2	True
Low2	High3	High3	True
Low1	High4	High4	True

The sensed data are evaluated using fuzzy, at the main sensor node and is sent to the base station. Fuzzy evaluation at each sensor node is evaluated during sleep mode and only if the fuzzy output is ‘true’, the aggregated data is compressed and sent to the base station during an active mode. The Mamdani’s fuzzy approach is used for data evaluating process and the system block is shown in Figure 4.

The fuzzy model consists of four processes such as:

1 fuzzification-the inputs are given with crisp value and changed into fuzzy sets

2 rule evaluation-the inputs are taken and applied to the antecedents of fuzzy rules and then it is applied to the consequent membership function

3 aggregation of output rule-it is involves merging of output of all rules

4 defuzzification-it is transforms the fuzzy set into a crisp value.

The linguistic variables for the fuzzy set are defined by the peak/threshold values by the format of (rainfall, moisture, pore pressure) Ramesh and Rangan (2014). We define fuzzy rules by sensed values only informed to base station only at peak/threshold values such as (20 mm, 0%, 0 kPa), (17 mm, 14%, 8.5 kPa), (14 mm, 28.5%, 17 kPa), (11 mm, 43%, 26 kPa), (8.5 mm, 57%, 34.5 kPa), (5.5 mm, 71.5%, 4 kPa), (2.9 mm, 86%, 51.5 kPa) and (0 mm, 100%, 60 kPa). The trapezoidal and triangular membership functions are employed for low1, low2, low3, low4, high1, high2, high3 and high4 variables and is shown in Figures 5(a) to (c). Based on the crisp inputs the possible outcomes are described and it is tabulated in Table 2. But the peak/threshold information's are transferred to base station, it is mentioned as 'true' values rather than this are denoted as 'false'. The possible true values are tabulated in Table 3.

5 Performance analysis

The network simulator (NS2) is used to simulate the proposed an energy efficient cluster based routing protocol for LMS for maximising the lifetime of network by reduce the link failure in terms of energy consumption and malicious attacks. We set up the simulation in an area of 1,000 square meters for a random waypoint sensor model with varying number of nodes and IEEE 802.11 MAC protocol is used for our implementation. The two ray ground transmission model is used with the transmission range 250 m and 11 Mbps bandwidth. Different test scenarios are used for performance comparison and the test scenario is described in Table 4.

Table 4 Test scenarios for performance comparison

Scenarios		*No. of sensor used*	*Type of sensor used*	*Threshold level*	*Frequency of sampling*
1	1	100	Rain gauge	Both all, peak only sensed values	0–1/hr
	2	200	Rain gauge, moisture sensor	Both all, peak only sensed values	0–1/hr
	3	300	Rain gauge, moisture and pore pressure sensor	Both all, peak only sensed values	0–1/hr
2	1	0-500	Rain gauge, moisture and pore pressure sensor	All sensed values	1/sec
	2	0-500	Rain gauge, moisture and pore pressure sensor	Peak only sensed values	1/sec

Figure 6 Data gathering analysis of rain gauge only, (a) data transmission rate (b) link failure (c) energy consumption (d) network life time

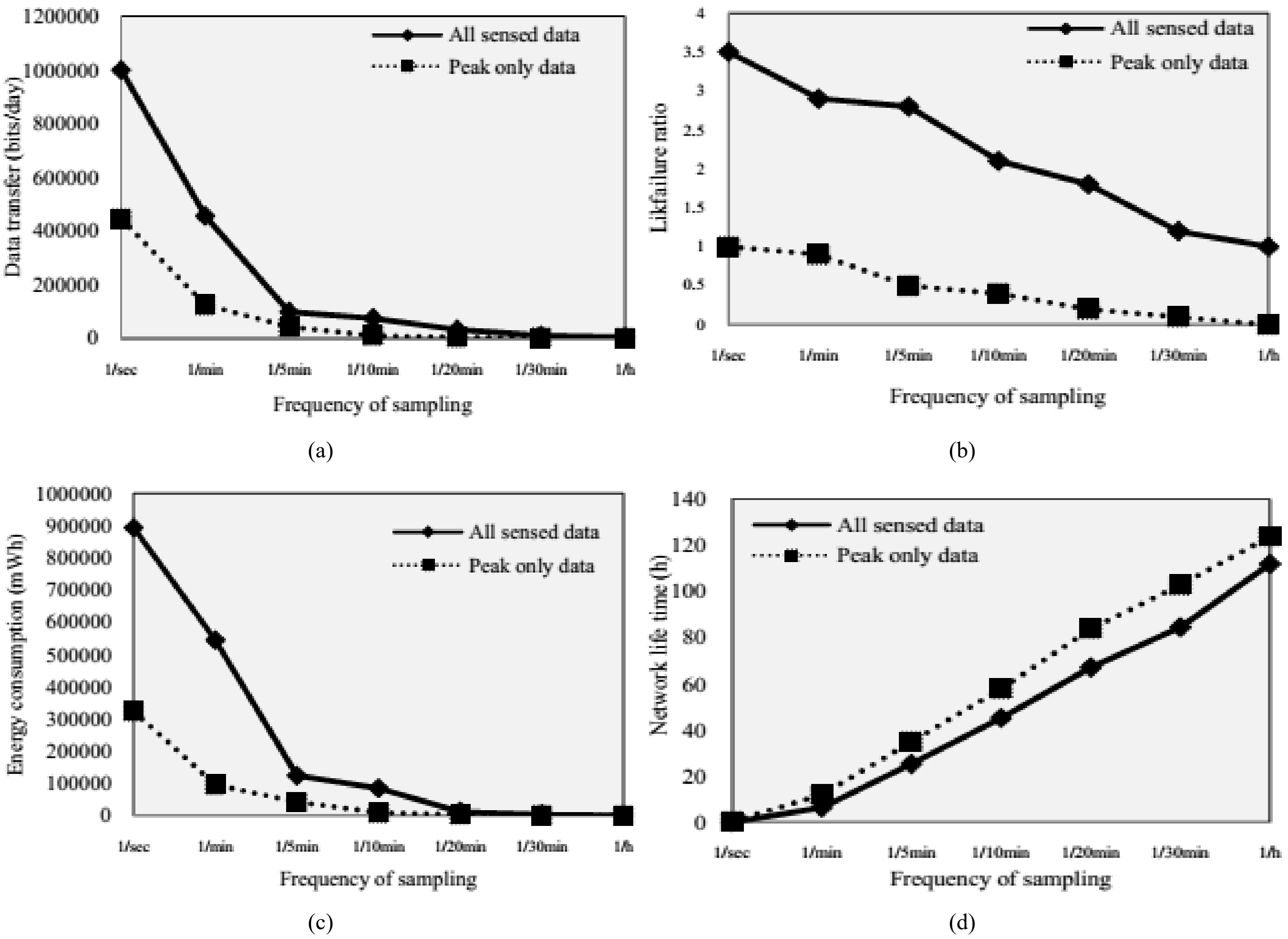
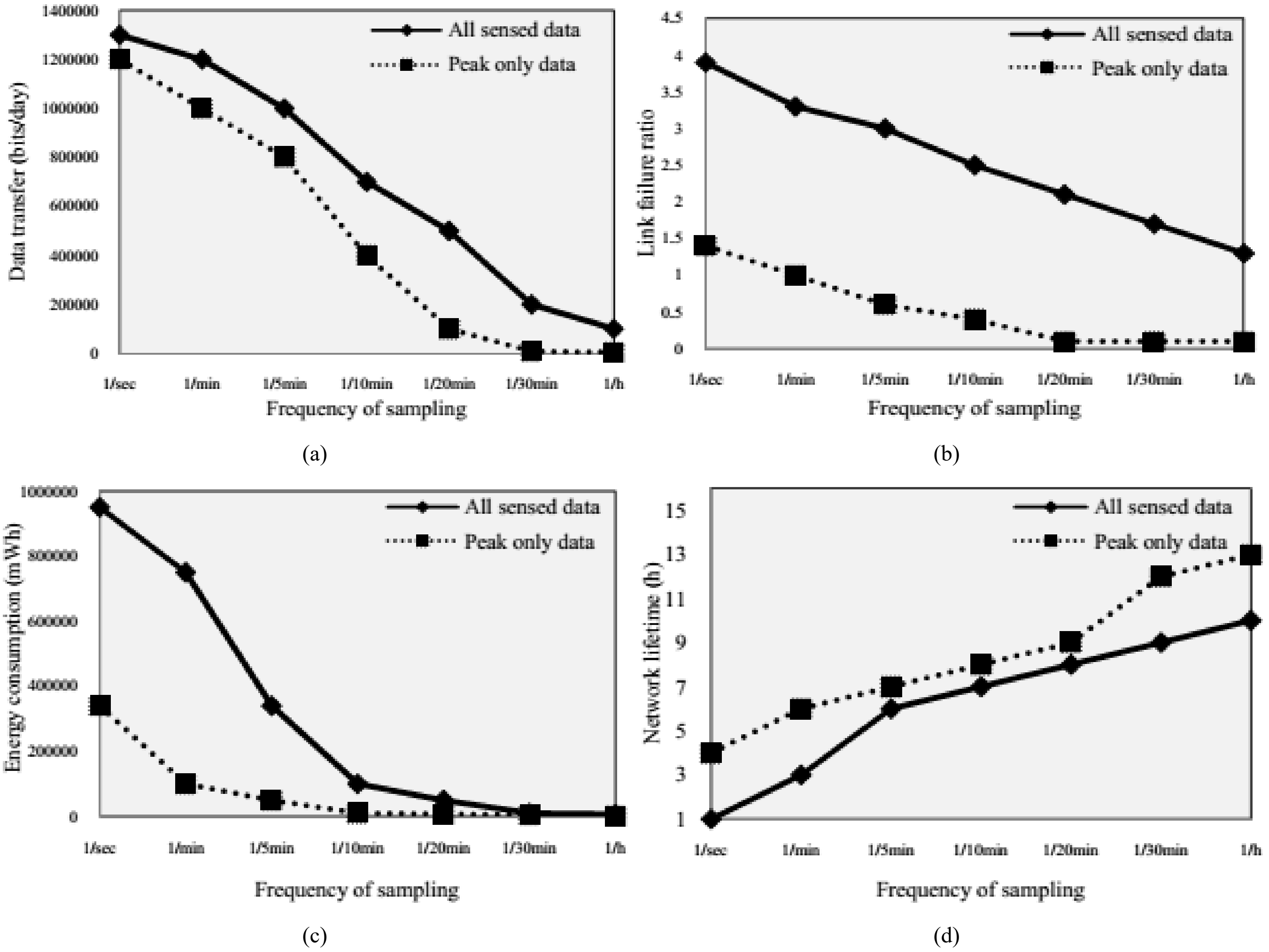


Figure 7 Data gathering analysis of double senor nodes, (a) data transmission rate (b) link failure ratio (c) energy consumption (d) network life time



5.1 Test scenario-1

In this subsection data gathering function of proposed LMS is analysed by different types of sensor nodes with the fixed numbers. The different sensors are used to sense the land slide levels in the network area and then the sensed information's are transmitted to BS. Further the BS forward collected information's into landslide monitoring centre. Here the collected information's are effectively identified and decide which information's are true (related to our peak/threshold values) and it is forward to peoples in nearby land sliding area. The false information's are avoided in the fuzzy based data mining/aggregated phase. The performance of this scenario is analysed by data transfer rate, link failure, energy consumption and network life time.

- *Data transfer rate* is the speed with which collected sensed information's can be transmitted from sensor nodes to base station.
- *Link failure:* in routing path, the link failure it is occurs due to unwanted malicious attacks and energy consumption of sensor nodes.
- *Energy consumption* is the amount of energy consumed by the sensor nodes to transmit the sensed landslide information's to the base station.
- *Network life time* define by the time till the death of the last sensor.

5.1.1 Single sensor-rain gauge only

The rain gauge single sensor is used to gather all information about rainfall levels in the covered network area with constant 100 nodes and varying sampling frequencies in terms of 0, 1/sec, 1/5 min, 1/10 min, 1/20 min, 1/30 min and 1/hr. The performance analysis, data transfer rate, link failure, energy consumption and network life time of proposed LMS is shown in Figure 6. The plot clearly depicts the performance of peak only sensed value rate is better than all sensed value rates.

5.1.2 Double sensor nodes – rain gauge and moisture sensor

The double sensors (rain gauge, moisture sensor) are used to gather all information about rainfall levels and soil moisture in the network area with constant 100 nodes and varying sampling frequencies in terms of 0, 1/sec, 1/5min, 1/10 min, 1/20 min, 1/30 min and 1/hr. The performance analysis, data transfer rate, link failure, energy consumption and network life time of proposed LMS is shown in Figure 7. The plot clearly depicts the performance of peak only sensed value rate is better than all sensed value rates.

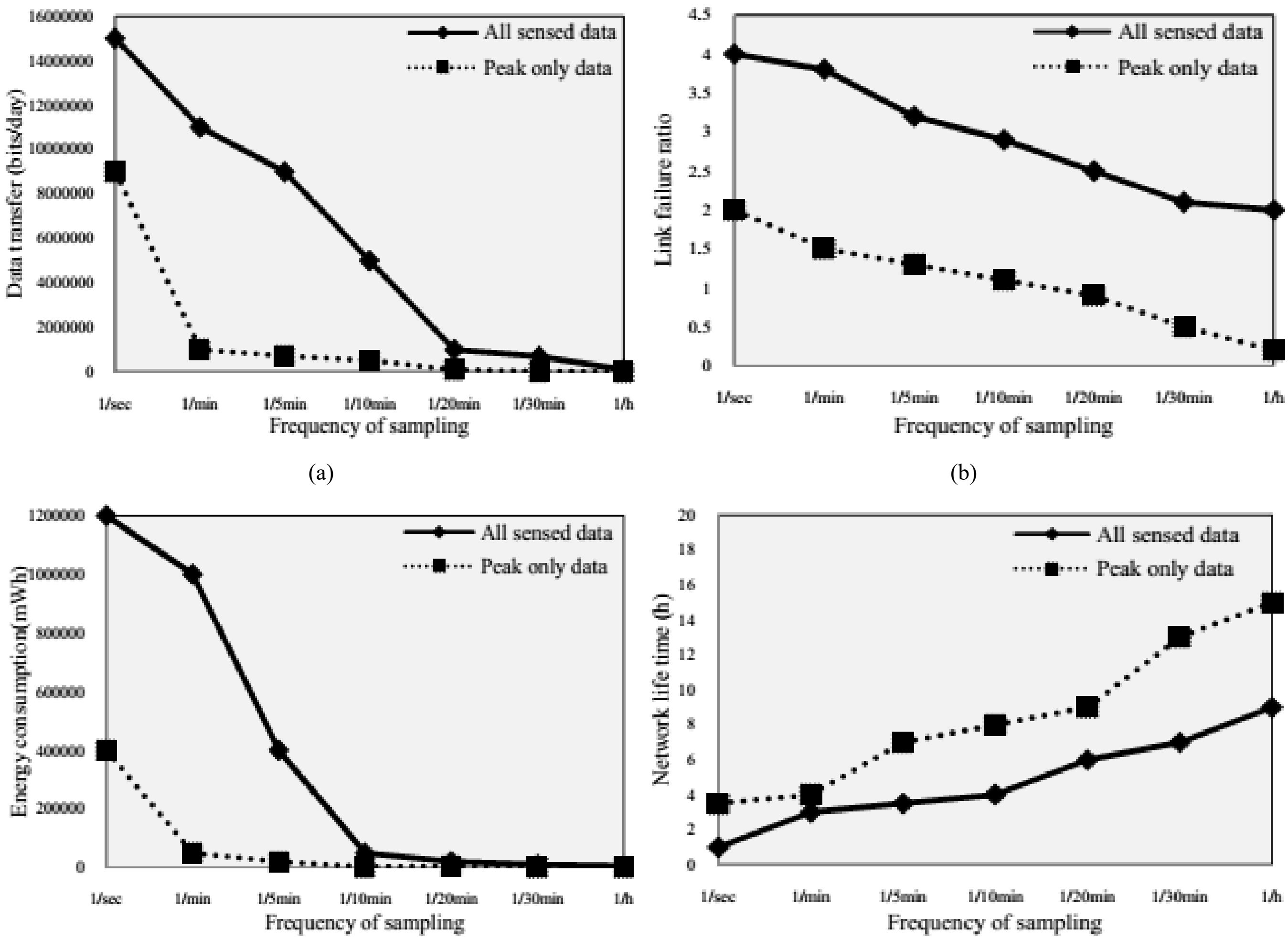
5.1.3 *Triple sensors – rain gauge, moisture sensor and pore pressure sensor*

The triple sensors (rain gauge, moisture sensor and pore pressure) are used to gather all information about rainfall levels, soil moisture and pore pressure in the network area with constant 100 nodes and varying sampling frequencies in terms of 0, 1/sec, 1/5 min, 1/10 min, 1/20 min, 1/30 min and 1/hr. The performance analysis, data transfer rate, link failure, energy consumption and network life time of proposed LMS is shown in Figure 8. The plot clearly depicts the performance of peak only sensed value rate is better than all sensed value rates.

5.2 *Test scenario-2*

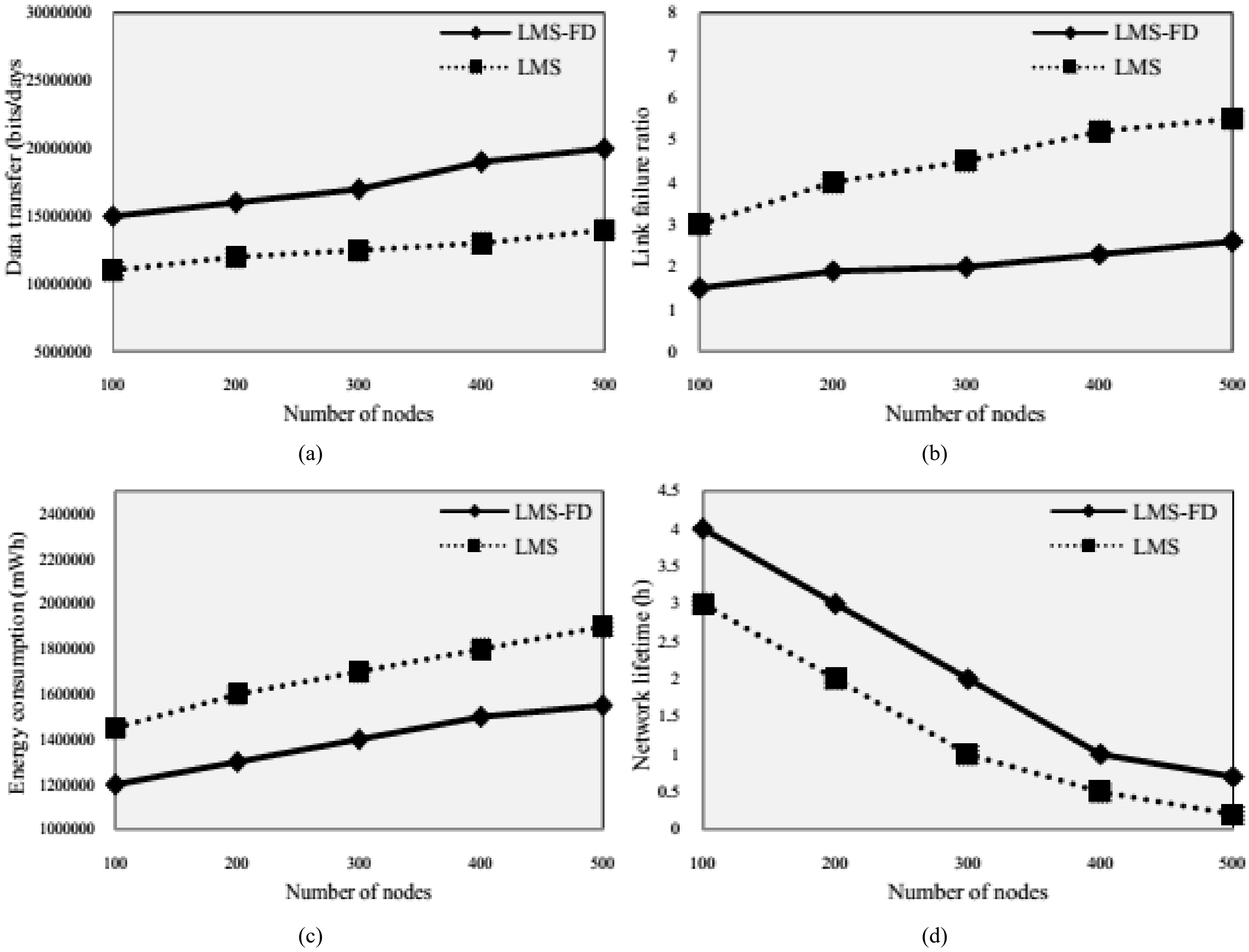
In this subsection performance of proposed LMS is analysed by different types of sensor nodes with the varying number of nodes. The different sensors are used to sense the land slide levels in the network area and then the sensed information's are transmitted to BS. Further the BS forward collected information's into landslide monitoring centre. Here the collected information's are effectively identified and decide which information's are true (related to our peak/threshold values) and it is forward to peoples in nearby land sliding area. The false information's are avoided in the fuzzy based data mining/aggregated phase. The performance of this scenario is analysed by data transfer rate, link failure, energy consumption and network life time.

Figure 8 Data gathering analysis of triple senor nodes, (a) data transmission rate (b) link failure ratio (c) energy consumption (d) network life time



(a) (b) (c) (d)

Figure 9 Performance analysis of all sensed values, (a) data transmission rate (b) link failure ratio (c) energy consumption (d) network life time



5.2.1 *Performance analysis of all sensed data gathering phase*

The triple sensors (rain gauge, moisture sensor and pore pressure) are used to gather all information about rainfall levels, soil moisture and pore pressure in the network area with constant sampling frequency as 1/sec and varying number of nodes, like 100, 200, 300, 400 and 500. The performance analysis, data transfer rate, link failure, energy consumption and network life time of proposed LMS using fuzzy data mining (LMS-FD) is shown in Figure 9. The plot clearly depicts the data transmission rate is high, the link failure, energy consumption is very low and network lifetime is high compare to LMS in Figures 9(a) to 9(d) respectively.

5.2.2 *Performance analysis of peak only sensed data phase*

The triple sensors (rain gauge, moisture sensor and pore pressure) are used to gather all information about rainfall levels, soil moisture and pore pressure in the network area with constant sampling frequency as 1/sec and varying number of nodes, like 100, 200, 300, 400 and 500. The performance analysis, data transfer rate, link failure, energy consumption and network life time of proposed LMS using fuzzy data mining (LMS-FD) is shown in Figure 10. The plot clearly depicts the data transmission rate is high, the link failure, energy consumption is very low and network lifetime is high compare to LMS in Figures 10(a) to 10(d) respectively. Then the collected data are efficiently handled in fuzzy data mining algorithm and which reduce the false information about measured network area, the snap of proposed monitoring display is shown in Figure 11.

Figure 10 Performance analysis of peak only sensed values, (a) data transmission rate (b) link failure ratio (c) energy consumption (d) network life time

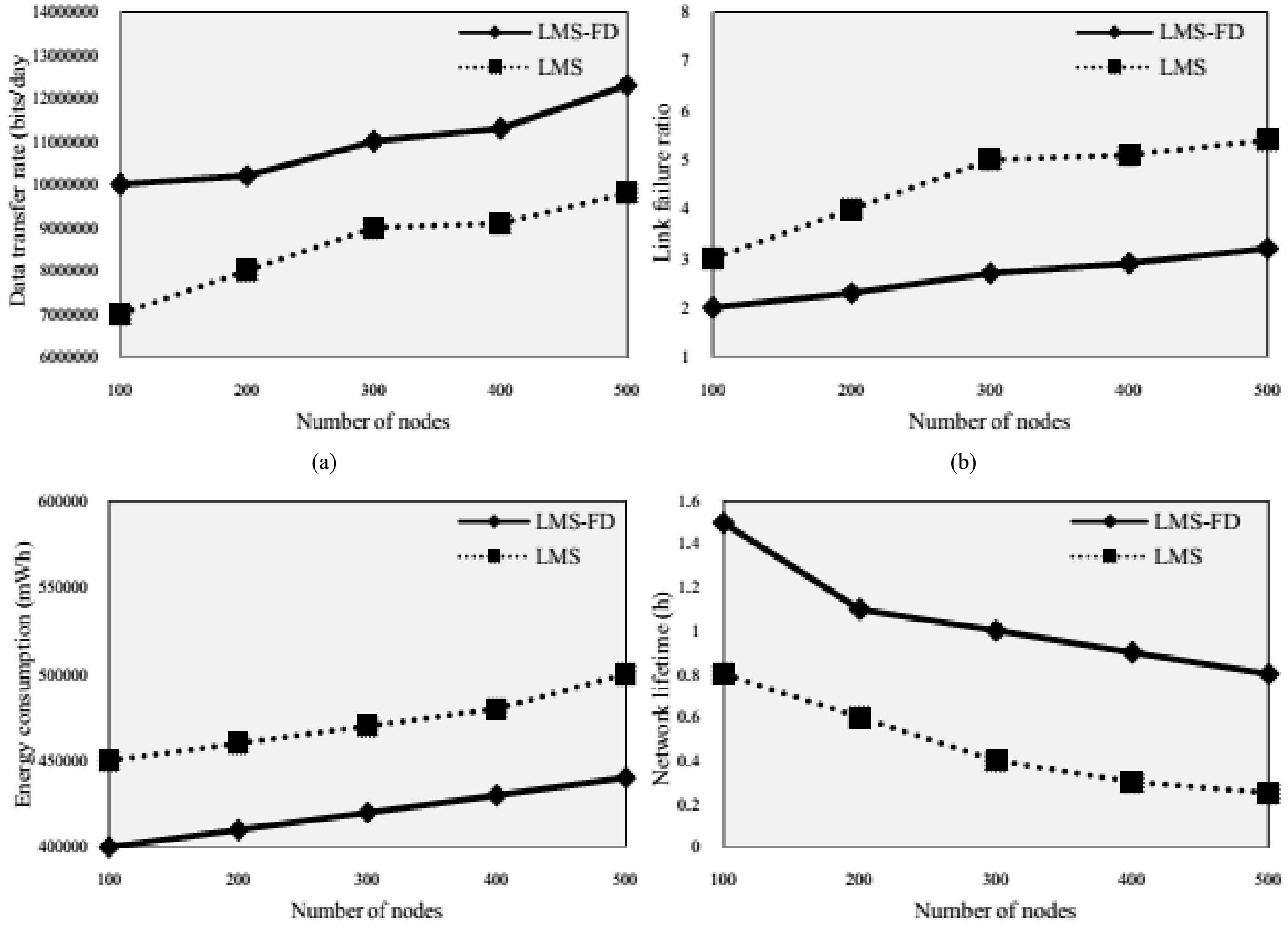
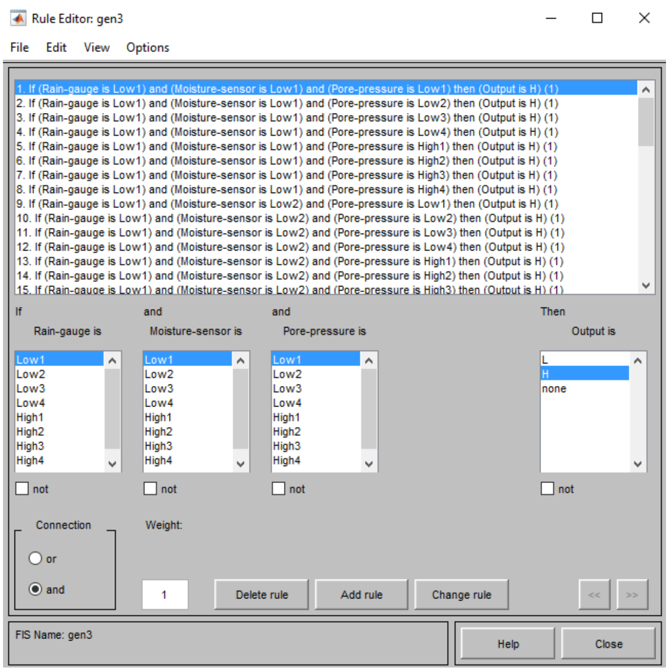


Figure 11 Landslide monitoring display with the peak value result (see online version for colours)



6 Conclusions

We proposed enhanced LMS with maximising the life time of sensor nodes by avoiding link failure in the routing protocol. The three different sensors, rain gauge, moisture sensor and pore pressure sensor used for sensing rainfall, soil moisture and pore pressure respectively. The cluster based routing protocol with the sensor nodes is capable of data acquisition, data storage, data processing, and wireless data transmission. Then collected sensed data are aggregated using fuzzy data mining technique which maximise lifetime of all sensor nodes in the network area. Data gathering analysis shows that all sensed data affects sensor performance compare to peak only sensed data. Performance analysis shows that the proposed LMS efficient for more number of sensor nodes in terms of network life time, sensor node life time, data transmission and energy consumption.

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