# An Open Source Wireless Sensor Network for Data Analytics with Uncertain Management using Markov Decision Processes in Infrastructure and Environmental Monitoring

C. Nithya Praba and M. Devapriya

**Abstract**--- In recent work Wireless Sensor Networks (WSNs) is designed for transportation and environmental monitoring and have develop over numerous generations. Current demand designed for WSNs, e.g., in smart cities, introduces they necessitate designed for sensing systems with the purpose of be able to cooperate among the surrounding environment's dynamics and objects. So sensing unit in WSN is optimized through low power designed for tremendously long-term deployments. To reduce power consumption in WSN numerous features, such as information compression and online reconfiguration, are integrated to WSN. But still, if the services become high due to the following constraints such as long service time and low maintenance cost, WSNs need adaptive methods to reduce the power consumption, packet loss, and resource. To solve this problem in recent work proposed a Real-time data visualization and investigative through a representational state transfer (RESTful) Application Programming Interface (API). For efficient data transmission to cloud server, SnowFort, an open source WSN, is introduced for monitoring transportation and location. But in this work still the packet loss is not solved because of uncertain problem, to solve this problem in this work Markov Decision Process (MDP) method have been introduced for monitoring transportation to minimize packet loss. In addition, develops a MDP algorithm robust toward decrease data loss and validates it in a simulation setup. Explain the use of MDP designed for the control of sensor nodes in a WSN second-hand for environmental monitoring. The MDP is designed in the direction of collect best possible information regarding the sensor nodes at the same time as guaranteeing an utmost lifetime of with less packet loss. Extend the MDP through improved resistance toward communication packet missing and experimented using Network simulation setup.

**Index Terms**--- Sensor System Integration, Structural Health Monitoring, Wireless Sensor Networks (WSNs), Data Analytics, Markov Decision Process (MDP) Framework, Sensing Platform

## I. INTRODUCTION

A Wireless Sensor Network (WSN) is a collection of specific transducers by means of a communications transportation anticipated toward examine and record conditions on varied locations. Usually monitored characteristics are heat, moisture, pressure, wind path and velocity, light concentration, impurity levels and very important body functions. Wireless sensor networks (WSNs), may be comprised by hundreds or maybe thousands of ad-hoc sensor node devices, working together to accomplish a common task. Self-determination, self-optimizing and fault-tolerant is the most important characteristics in WSN. Extensive networks of low-cost wireless sensor devices suggest a considerable chance in the direction of examine more precisely the surrounding

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substantial phenomena's when compared in the direction of traditional sensing methods [1]. WSN has its individual design and source constrains [2]. Specification of the design constrains are associated through the principle and the distinctiveness of the fitting environment. The fitting environment and environmental environment decide the dimension of the WSN, the operation schema and the network topology. Several number of methods have been investigated to WSN along with resource constrains via introducing innovative design methodologies and applications [3].

Among them all of the methods and design some of them are applied to environmental monitoring applications [4] and have applied to several filed such as buildings [5], habitation [6], bridges, traffic [7], pipelines [8], volcanoes [9], and environment [10]. So the major important part of wireless monitoring environment system consists of wireless sensing units, wireless communication networks, and Decision Support Systems. During these steps large scale implementation of WSN knowledge necessitate a stage with the intention of addresses numerous challenges:

1. Durability: sensing units necessitate toward function designed for months to years not including battery alternate.
2. Reliability: sensors necessitate toward consistently deliver information over damaged wireless communication channels.
3. Adaptability: dynamically adding up and removing sensors toward the scheme be supposed to be easy.
4. Intelligence: scalable real-time substantiation, examination and dispensation of the information need to be obtainable.
5. Simplicity: customizing, installing, deploying and preserve the scheme are supposed to be straightforward.

SnowFort is an Open source framework designed for information analytics is introduced in [11] to transportation and ecological monitoring. It makes straightforward scalable achievement and exploitation of WSN to gather, purify, examine and environmental information in real-time. In adding together SnowFort also supports a diversity of hardware platforms and be able to be incorporated through existing methods. In adding together, the systems are not optimized toward deal with numerous issues common in communications and environmental applications.

Information processing in real-time is supported by a Decision Support System (DSS) with the intention of depending in earlier analytics frameworks. SnowFort is capable in the direction of hold up to 54 sensing units for each extremely low cost BS. The DSS supports the real-time investigation and visualization of data beginning numerous large amount wireless monitoring systems by means of a web interface. In this paper work introduces a new decision methods based on the Markov Decision Process (MDP) to estimate the power consumption of each nodes in wireless sensor nodes at the rate of the uncertainty. Since the power consumption of the MDP is synchronized and needs to satisfy two major constraints (1) the present and projected ecological position of the node and (2) the necessary smallest amount lifetime of the system.

## II. BACKGROUND STUDY

Environment monitoring is a natural candidate for applying wireless sensor networks, since the physical variables that must to be monitored, e.g., temperature. They are usually distributed over large regions. Environmental monitoring applications can be broadly categorized into indoor and outdoor monitoring. Indoor monitoring applications typically include buildings and offices monitoring.These applications involve sensing temperature, light, humidity, and air quality. Other important indoor applications may include fire and civil structures deformations detection. Outdoor monitoring applications include chemical hazardous detection, habitat monitoring, traffic monitoring, earthquake detection, volcano eruption, flooding detection and weather forecasting. When monitoring the environment, it is not sufficient to have only technological knowledge about WSN and their protocols. It

is also necessary the knowledge about the ecosystem.

Illinois Structural Health Monitoring Project (ISHMP) framework created at the University of Illinois at Urbana-Champaign is an open-source WSN stage intended for auxiliary checking [12]. It has been tentatively accepted for harm recognizable proof and limitation by [13] and [14]. Notwithstanding, ISHMP framework needs Decision Support System (DSS), which is a basic segment of today's remote observing framework and is incorporated in SnowFort [15] proposes a structure incorporates all the three parts needed for remote checking framework. Dissimilar to SnowFort, which underpins different gadgets and has web interface, this framework is an Open Software (OS) -particular executable project. Further, the system can't be coordinated with any current framework that has been proposed.

The indoor wireless monitoring scheme in [16] confine the morphology of buildings designed for fast improvement and flexible management. Together frameworks successfully and capably formulate decisions based on sensing information though, they do not deal with network dependability and information synchronization [17] is an indoor Heating, Ventilation and Air Conditioning (HVAC) scheme through Decision Support System (DSS) at the back-end. On the other hand, this HVAC scheme depends on WiFi logs, not sensing units is an outdoor wireless scheme designed for environmental monitoring. It accomplishes dependable communication and information synchronization through customized Medium Access Control (MAC), which is comparable to SnowFort. This system is confirming through experimentation and accomplishes the longterm operation through employing the solar panels. In SnowFort, the wireless sensors are position in the meadow. The dependable wireless communication is utilized designed for information acquisition through power aware optimization and information synchronization mechanism. The building managing scheme is able to be achieved on the web server.

A time-domain algorithm towards notice the damage of a formation using WSN is discussed in [18]. This method extorts harm sensitive features beginning numerous accelerometers and makes use of hypothesis tests towards make a decision whether damages occur. The structure existing in [19] make use of harm sensitive features designed for testing as well, and in a chronological way there a frequency domain distributed algorithm designed for the harm discovery and is validated through by means of the Illinois Structural Health Monitoring Project (ISHMP) system. In addition, confirm the performance of distributed algorithm through initiate packet loss.

Rajeev Piyare et al [20] examine the WSN applications in significant region such as healthcare, armed forces, significant infrastructure monitoring, atmosphere monitoring, and industrialized. Appropriate to a number of the restrictions of WSNs in terms of memory, energy, computation, communication, along with scalability, well-organized managing of the huge number of WSNs information in these areas is a significant issue. It proposes a structural design used for incorporate Wireless Sensor Networks through the Cloud. Representational State Transfer (REST) architecture based Web service is second-hand towards examine e-health care examination and smart situation.

## III. PROPOSED UNCERTAIN MANAGEMENT USING MARKOV DECISION PROCESSES

In this work proposed a novel Markov Decision Processes (MDP) for solving uncertain resource management and power consumption problem in WSN. In order to perform this task , proposed schema classifies the WSN into various steps such as information exchange , resource management and power optimization. MDP in addition review well-organized algorithms to regard as the substitution among energy utilization, packet loss and resolution optimality in WSNs. Through contrast, the MDP is second-hand designed for stochastic optimization, i.e., in the direction of attain the most excellent actions to be taken

known particular objectives to find uncertainty. The MDP is performed based on the behavior of the stochastic decision procedure of an agent cooperate through an environment. In each step of MDP proposed schema starts with decision state and the agent selects an achievement with the intention of obtainable state. After the completion of this step then agent obtain an instantaneous reward R and the scheme transits to a new state $s_0$ regarding to the transition probability $P^{a}_{s,s'}$ . Designed for WSNs, the MDP is second-hand in the direction of model the interaction among a nodes and their surrounding environment (See Figure 1)

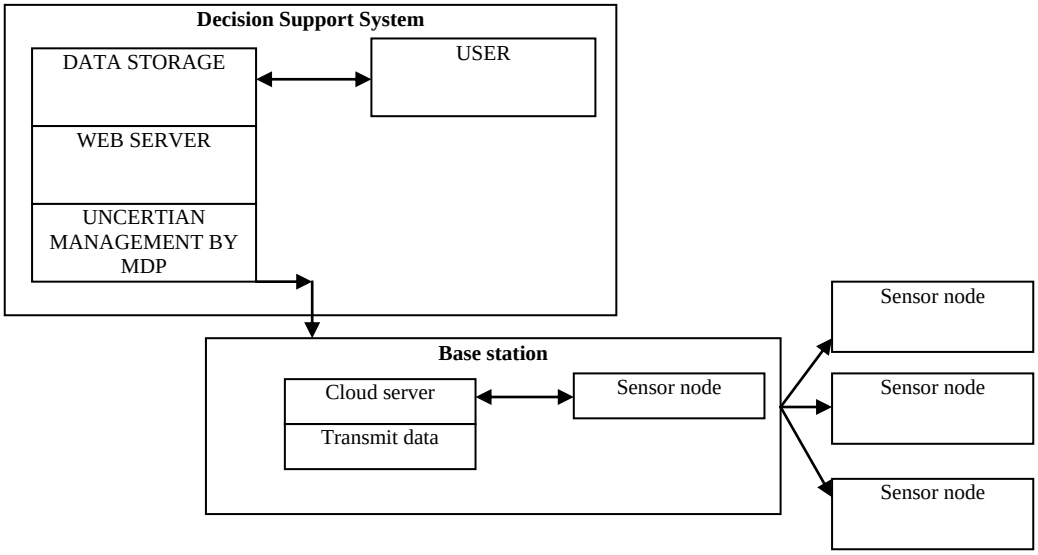


Figure 1: Architecture Diagram of Proposed System

SnowFort is an Open source framework designed for information analytics is introduced in [11] to transportation and ecological monitoring. It makes straightforward scalable achievement and exploitation of WSN to gather, purify, examine and environmental information in real-time. In adding together SnowFort also supports a diversity of hardware platforms and be able to be incorporated through existing methods. In adding together, the systems are not optimized toward deal with numerous issues common in communications and environmental applications. In this work, robustness and dependability designed for the scheme are achieved through careful devise of the wireless communication protocol, in exacting the Medium Access (MAC) layer. At the same time effortlessness and scalability is attained through ensuring a basic single-hop network topology depending on numerous base-stations. Cleverness is provided depending on high performance and information -processing in real-time environment. The SnowFort schema offers a high-level functions and Application programming Interface (APIs) in the direction of make straightforward custom development.

Wireless Sensor Mote: A wireless sensor mote is a type of battery-powered based wireless sensor system by means of wireless transceiver, and recollection. The major steps of the Wireless Sensor Mote are to gather the information about sensor nodes, constrict and broadcast them to a base station. In addition, the mote receives and accomplishes commands beginning the Base Station. In consists of several number of converters such as Analog-To-Digital Converters (ADC), Digital-To-Analog Converters (DAC), and Inter-Integrate Circuit (I2C) ports to connect and communicate by means of micro electromechanical sensors (MEMS), such as accelerometer and temperature sensor.

Cloud Server: In transportation and ecological monitoring function, the Decision Support System (DSS) is a significant component [21]. Organize huge networks requires construct to switch massive information flows,

real-time dealing out and visualization. In SnowFort, the cloud server is the most important information storage space and processing component. It moreover hand out as the web server designed for the front-end user boundary. The cloud server consists of three major steps a web server, information storage, and a numerical information processing unit. The web server receives information position beginning the base station and touch requests beginning end-users. In adding together, the web server sends commands beginning end-users to the base station. Numerous base stations are able to all together position to the server. In SnowFort [22] information communication protocol among the base station and the web server is the HTTPS protocol. The web server furthermore supports a representational state transfer (RESTful) Application Programming Interface (API) designed for information communication among systems.

The information storage unit has two databases designed for storing information. The primary database stores raw information in real-time. The second database stores cleansed real-time information which is able to be second-hand designed for arithmetical modeling. The web server introduces the formatted information addicted to the suitable database by means of calling a standard API. Currently, both databases are implemented in MySQL. The database update functions in SnowFort are able to be alternative through the model APIs of these systems. Consequently, the MySQL databases are able to be straightforwardly replaced with a variety of frequently second-hand distributed database systems. In adding together, SnowFort give interfaces designed for scientific calculation Matlab, to admission information. Such feature determinations advantage the applications similar to sensor appointment and optimization ([22]).

The SnowFort schema is able to be accessed beginning dissimilar locations and a diversity of devices. The SnowFort interface supports scheme configuration, information visualization, and user management. This information visualization panel permits users in the direction of view information of numerous sensors beginning diverse base stations in real time, view past information through diverse time segments', and check every example assessment. In addition, on this panel, users are capable to choose the information sources, place basic alarm rules, and execute basic filtering. The system and motes be able to be vaguely managed beginning the web interface, including rebooting individual motes, altering example frequencies, location mote IDs and configuring the communication scheme.

Markov Decision Process (MDP) is proposed in this work for uncertain management in environmental monitoring application and it consists of 4-tuple $(S, A, P, R)$. $S$ is a finite set of states, $A$ is a fixed set of actions with the intention of might be executed at every state. $P$ is a probability function with the purpose of defines how the state becomes changes during uncertain management $P : S \times A \times S \rightarrow [0, 1]$ . The probability of moving beginning of certain state $s$ to uncertain state $s'$ with action $a \in A$ is represented as $p(s, a, s')$. $R$ is the reward function: $R : S \times A \rightarrow R. R(s, a)$ in state $s$. A *policy* is denoted as a function with the purpose of decide an action designed for each state $s \in S$. The value of a policy is the determined via future rewards ,where the future rewards is denoted as the predictable sum of rewards converges in the direction of a restricted value, at $t$ steps $\gamma_t, 0 < \gamma < 1$ ,$\gamma$ is called the discount factor. The assessment of a state s below policy π, represented through $V^{\pi}(s)$ , The value function calculates the action toward be executed in state s below policy π:

$$argmax_{a \in A}(R(s, a) + \gamma \sum_{s' \in S} p(s, a, s')V^{\pi}(s)$$

$$V(s) = max_{a \in A}(\sum_{s' \in S} p(s, a, s')[R(s, a) + \gamma V(s')])$$

At iteration $k > 0$, the value function is updated as follows

$$V_k(s) = max_{a \in A}(\sum_{s' \in S} p(s, a, s')[R(s, a) + \gamma V_{k-1}(s')])$$

As $k \to \infty, V_k$ produces optimal results at every state of a sensor mote is denoted as state vector $(t, h, p). t \in \{t_1, \ldots, t_T\}$ indicate the time of the system . $h \in \{h_1, .., h_H\}$ is a determine of the uncertain state of the nodes at time-step, and $p \in \{p_1, \ldots, p_P\}$ is the amount of energy required to complete the environmental monitoring process. The transitioning probability from state $(t_i, h_i, p_i)$ to state $(t_j, h_j, p_j)$ at the rate $a \in A, p((t_i, h_i, p_i), a, (t_j, h_j, p_j)$ , is denoted as $p_T\,(t_i, t_j) p_H(h_i, h_j) p_P\,(p_i, a, p_j)$ *where*

$$p_T(t_i, t_j) = \begin{cases} 1\,, if\ i = j = T \\ 1, \quad if\ j = i + 1 \\ 0\ otherwise \end{cases}$$

$$p_H(t_i, t_j) = \begin{cases} p_H^{change}\ , if\ i = j \\ 2p_H^{change}, \quad if\ i = H, j = H - 1 \\ p_H^{change}\ if\ |i - j| = 1 \end{cases}$$

$$p_P(p_i, a, p_j) = \begin{cases} 1\,, if\ i = P \\ p_P(a), \quad if\ i = j \\ 1 - p_P(a)\ if\ j = i + 1 \\ 0\ otherwise \end{cases}$$

Thus, $p_H^{same}$ and $p_H^{change}$ be the probability value of certain and uncertain state in environmental status respectively. The rate of energy consumed by DSS is modeled via the reward function and it is calculated as

$$R(t, h, p), a) = \begin{matrix} -\mathrm{R}^{\mathrm{powerout}}\ \text{if p = P, t} < T \\ k_R.\,a.\,h\,, otherwise \end{matrix}$$

where $k_R$ is a constant of proportionality

In this research work , MDP is considered as the centralized controller [23] to monitor uncertainty for environmental monitoring via specifying stochastic model with criticality of the information and the energy consumption of the sensor. For each state-action pair $(s, a)$, specifies its "Q". When the agent perform uncertain management task $a$ in state $s$, receives reinforcement $r$ and progress to state $s'$, the subsequent keep informed rule is useful:

$$V(s) = \max_{a \in A} Q(s, a)$$

where , $0 < \alpha < 1$ , $Q$ values belongs to the optimal values and it is updated an immeasurable number of times. During the this process in MDP, the agent has to construct a transaction among examination and development of the policy with the intention of being learned, i.e., whether to perform the learned policy on a state. This ensures with the intention of the Q-values designed for each and every one states converge faster when compare to existing states in a learning trial.

## IV. Simulation Results

In order to perform experimentation work in this work prefer an earlier work [24], an emulation platform be able to decrease the improvement time of WSN. The emulation is able to be utilizing through other SnowFort users as well. Set up a network through 16 Telosb motes is illustrated in Figure 2. Mote 1 is considered a base station. The other 15 motes are second-hand designed for information collection and dispersed in an area of $150 \times 130$ square meters. The packet sequence number is second-hand in the direction of trace missing packets. When the base station notices the discontinuity of packet sequence numbers, a missing packet is acknowledged. Each and every one raw information is transmitting not including compression. The dimension of the information frame payload is maximized. This setup helps us in the direction of discover a scenario through utmost power consumption.

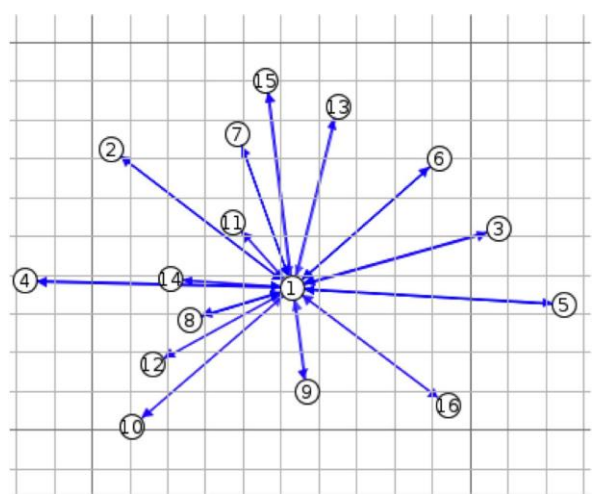


Figure 2: Emulation Topology Mote 1 is a base Station

Power Consumption: Designed for Telosb mote with four operation states such as CPU active, CPU inactive, $I_{active}$ $T_{active}$

$$E_{total} = E_{active} + E_{inactive} + E_{TX} + E_{RX} + E_{Sensor}$$

$$= V\_supply \times (I_{active} T_{active} + I_{inactive} T_{inactive} + I_{TX} T_{TX} + I_{RX} T_{RX}) + V_{Sensor} I_{Sensor} T_{Sensor}$$

$$= T_{total} P_{total}$$

$$= T_{total} \times (P_{active} + P_{inactive} + P_{TX} + P_{RX} + P_{Senso}$$

where $E_S, P_S,$ and $I_S$ is represented as energy consumption, the power, and the current utilization, in the operation status S correspondingly, $V_{supply}$ represented as the deliver voltage, which characteristically is 3 volts, $V_{Sensor}$ is represented as the make available voltage of sensor by means of the pin of mote, and TS is represented as the time continue in the process status S with active status, inactive position, transmission (TX) position, receipt (RX) position and sensor. In adding together, $T_{total} = T_{active} + T_{inactive}$ . The power consumption of together I2C and ADC sensors is represented as $E_{Sensor}$ . For sensors, the development time $T_{Sensor}$ is $T_{total}$ . evaluate the performance of proposed and existing methods in two major ways. In initial step of the work measure the performance of the schemas in terms of the communications, power expenditure and synchronization performance. Subsequent, measure network performance using Packet Drop Rate (PDR),

$$PDR = \left(1 - \frac{Number\ of\ packets\ received}{Number\ of\ packets\ transmitted}\right. \times 100\%.$$

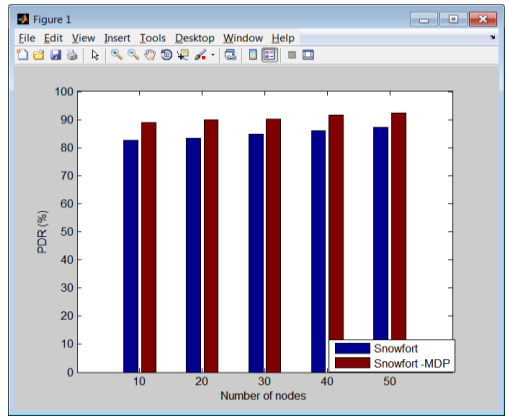


Figure 3: PDR vs Methods

Via the repeating experimentation work in several times, the PDR of proposed MDP schema and existing SnowFort is determined , it shows that the proposed MDP methods attains high, when compare to existing SnowFort. Designed for applications necessitate higher accuracy. Figure 3 shows PDR results between, proposed SnowFort –MDP and SnowFort system is able to support up to 54 motes on 32Hz in the simulation configuration. In simulation configuration, the PDR of proposed SnowFort -MDP is 92.37 % in NS2 emulation and SnowFort is 87.28 % for 50 nodes results are shown in Table 1.

Table 1: PDR vs Methods

| No. of nodes | PDR (%) | |
|---|---|---|
| | Snowfort | Snowfort -MDP |
| 10 | 82.56 | 88.91 |
| 20 | 83.27 | 89.82 |
| 30 | 84.85 | 90.21 |
| 40 | 86.12 | 91.51 |
| 50 | 87.28 | 92.38 |

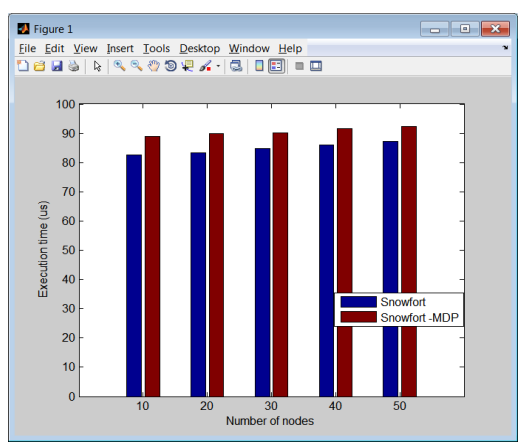


Figure 4: Execution Time vs. Methods

Via the repeating experimentation work in several times, the execution time of proposed MDP schema and existing SnowFort is determined , it shows that the proposed MDP methods attains less average time delay of $58\mu s$ , when compare to existing SnowFort. Designed for applications necessitate higher accuracy. Figure 4 shows execution time between, proposed SnowFort –MDP and SnowFort system be able to support up to 54 motes on 32Hz in the simulation configuration. In simulation configuration, the execution time of proposed SnowFort -MDP is $58\mu s$ in NS2 emulation and SnowFort is $56\mu s$ for 50 nodes results are shown in Table 2.

Table 2: Execution Time vs Methods

| No. of nodes | Execution time ($\mu$s) | |
|---|---|---|
| | Snowfort | Snowfort -MDP |
| 10 | 84 | 32 |
| 20 | 86 | 38 |
| 30 | 88 | 42 |
| 40 | 92 | 48 |
| 50 | 93 | 56 |

The data Compression Ratio (CR) is determined as,

CR=(1−Total number of bits transmitted Total number of bits sampled) × 100%.

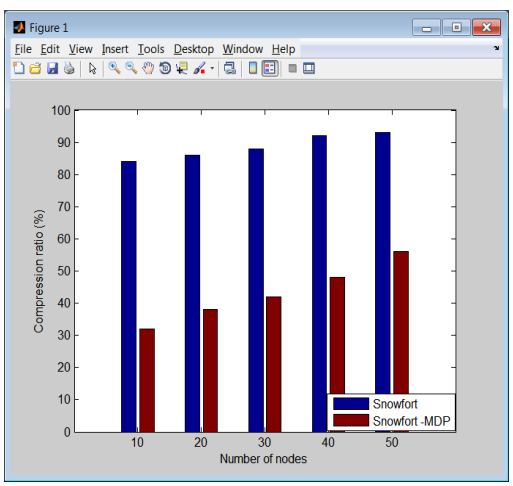


Figure 5: Compression Ratio vs. Methods

Via the repeating experimentation work in several times, the compression ratio of proposed MDP schema and existing SnowFort is measured , it shows that the proposed MDP methods attains a high compression ratio (CR) when compare to existing SnowFort. Designed for applications necessitate higher accuracy. Figure 5 shows Compression ratio between, proposed SnowFort –MDP and SnowFort system be able to support up to 54 motes on 32Hz in the simulation configuration. In simulation configuration, the Compression ratio of proposed SnowFort -MDP is 92.53 % in NS2 emulation and SnowFort is 85.51 % for 50 nodes results are shown in Table 3.

Table 3: Compression Ratio vs. Methods

| No. of nodes | Compression ratio (%) | |
|---|---|---|
| | SnowFort | SnowFort -MDP |
| 10 | 84 | 32 |
| 20 | 86 | 38 |
| 30 | 88 | 42 |
| 40 | 92 | 48 |
| 50 | 93 | 56 |

## V. Conclusion and Future Work

In this research work introduce a new Markov Decision Process (MDP) schema for uncertain management in WSN for environmental monitoring and SnowFort is introduced to perform the communication interface between the user and the wireless sensor node at receiver side. Snowfort initiate a novel architecture designed for the incorporation of together a WSN and a Decision Support System, by means of real-time visualization, investigative, and communication over a web interface. In addition the proposed MDP also introduces a time division based communication scheme, TDMA to improve the results of WSN in terms of the reliability and scalability to expand the lifetime. Packet loss minimization is performed through a MDP mechanism with the purpose of integrates uncertainty, and has been experimented via NS2 simulation tool. In addition the proposed work introduces a MDP be able to examine sensor information rates in a WSN designed for environmental monitoring. The controller was able to promise the least amount lifetime of the scheme through changing the decision on which the information is transferred beginning cloud server to sensor node of the environmental information. Future work in WSN environmental monitoring must comprise additional examination addicted to node platforms, the balancing of

uneven energy distributions and long-term behavioral learn of scheme in real-world employment. Designed for node platforms, it may exist of exacting concentration to examine hybrid architectures with message communication control is handled centrally.

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