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Naive Bayes Based QoS for Wireless Sensor Networks

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***Abstract*—**Sensor networks is widely used in real-time applications that have made emergent of Quality of Service (QoS) based communication schemes. Recently QoS in sensor network becoming an interesting topic among the research community. This paper proposes a Naïve Bayes based QoS mechanism, which is suitable for both real-time and non-real-time applications. The proposed mechanism achieves the desired QoS by selecting the neighboring nodes in a way to meet the required QoS. Performance of the scheme is evaluated through simulations. The results provide insights on the performance of the system based on different evaluation metrics such as end-to-end delay, packet delivery ratio and the node failure probabilities. The results demonstrate that the scheme is able to outperform the compared mechanisms such as Multi-constraint Multi-Path (MCMP) routing protocol and energy efficient QoS aware routing protocol (EQSR) using both real time traffic (EQSR-RT) and non-real time traffic(EQSR-NRT).

***Keywords*—**Sensor Network, Wireless, Quality of Service, Naive Bayes classifier, Real-time applications

I. INTRODUCTION

Wireless sensor networks consist of large number of tiny wireless devices, low powered capable of sensing and monitoring environment [1]. The applications of sensor networks include but not limited to military surveillance, health care, transportation and logistics and smart buildings. The work in this thesis addresses the problem of routing real-time data such as video and imaging though maintaining the quality of service (QoS) of the application. QoS defines the overall performance measurement of a network that satisfies the objectives of a sensor network application.

On the other hand, with the specific properties of sensor network devices such as limited power, stringent computational capability, high network density, and scalability pose unique challenges in designing and managing sensor networks [2]. These challenges demand energy aware QoS based design protocols. Recently most of the researches have discoursed on the efficient utilization of sensor's energy and maximizing its lifetime. However, real-time sensor network applications may contain delay sensitive and delay tolerant data. For example, the data that carries the information about an indication of fire should be reported to the user within time limits. Any delay in routing the data may cause failure in taking corrective actions and the damage will be heavy [3]. Therefore, QoS routing is one of the most important aspects of research community more recently. In this paper a solution that effectively improves the QoS approach based on NB classification technique is presented. The idea is to seamlessly integrate the QoS requirement into the NB classifier and based on the prediction probability the next hop neighbor is selected so that it helps to forward the data to the destination with the required QoS requirements.

The rest of the paper is organized as follows, Section II presents a brief description of related QoS schemes, Section III describes the methodology and algorithm of the proposed scheme, Section IV describes the results and discussions and Section V Concludes the paper.

II. RELATED WORK

In Sensor network to support real-time applications, the routing mechanisms should deliver the data with high performance in an energy efficient manner [4]. The energy efficient state of the routing mechanisms can be categorized into different types of studies such as, QoS routing, energy based routing, topology based cluster or grid and social network.

Even though providing and maintaining QoS during the period of entire application is a difficult task, there are few approaches in the literature. The typical one for such scheme is QoS assurance routing for multimedia sensor networks. The design is the outcome of the similarity analysis between social network and multimedia sensor network. The authors

[5] designed a trust estimation model based on the design which uses clustered hierarchy to achieve the QoS required parameters. A localized quality of service routing protocol for wireless sensor network [6] targets the applications having different types of data traffic. The protocol differentiation according to the data type to achieve QoS is metric for each traffic. The advantage of the scheme is it uses geographic information, so that it eliminates the need for collecting routing information. The protocol is able to work with any MAC protocol provided with an ACK mechanism. Tom et al [7] came up with a new cross layer design for heterogeneous applications based on controlling and interacting among the different layers and demonstrated that the system achieves the desired performance without compromising the overall system design.

Hybrid medium access [8] combines contention-based and time division based protocols to expedite packet delivery. HMAC scheme is able to improve the performance without deviating network traffic quality. Adaptive fault tolerance QoS [9] satisfies the requirements based on hop-by-hop data delivery by removing the path redundancy between the source and the destination. QoS enhanced base station controlled dynamic clustering protocol utilizes the clustering approach and delicates the energy intensive tasks such as routing related computations to base station. The scheme supports QOS using delay and bandwidth. A dynamic programming [10] based approach based on markov decision process that finds the optimum policy to achieve the required performance in a sensor node.

III. METHODOLOGY

A. Neighbor Discovery

The neighbour discovery phase is initiated by the sink node. It is assumed that a unique id is assigned to every sensor node in the network before deployment. The sink node creates a control packet and copies its id to the header of the packet and also sets the location, hop count as zero. The control message is broadcasted to its neighbouring sensor node. The node within the transmission range of the sink receives the control message. In the next step, the sensor nodes receiving the control packet, updates the neighbouring list with the information such as node id and location*(x,y)* present in the packet. After receiving a control message, the node checks whether a control message is forwarded by itself recently. If it is not forwarded through a control message, then the node creates a packet and copies its node id, location to the header of the packet and sets the destination as sink and also increments the hop count value by one. The process is eventually repeated by all the nodes only once to avoid creating looping among the packets. Finally, the sensor nodes' neighbouring list will be updated with neighbouring nodes information.

B. Path Renewal

In order to preserve the energy this work aims to reduce the traffic of the control messages. So instead of transmitting control messages periodically and updating the neighbouring nodes the authors have appended the residual energy and the link quality to the data message.

C. Path Selection

After the neighbour discovery phase any source will be able to know the available path to the destination. In this work, it is assumed that the available path equals the number of neighbours located towards the direction of the sink. Let *k* be the number of path available to reach the destination. Now the task is to select the best available path from k to reach the destination [11, 12]. The solution is based on Nave Bayes classification algorithm [13]. The next section reviews the classification algorithm that is followed by a solution based on the classification algorithm.

D. Naive Bayesian Classifier

Naïve Bayes classifier is based on Bayes theorem. According to the Bayesian theory, the maximum-a-posterior classifier minimizes the average classification error. Naive Bayes classification is mainly used for classification purposes. The Bayes theorem is given by definition is given by in Equation (1).

$$P\left(\frac{h}{d}\right) = \frac{P\left(\frac{D}{h}\right)P(h)}{P(D)} \quad (1)$$

Where *P(h)* is the prior probability of hypothesis h, P(D) is the prior probability of training data *D* and *P(D/h)* is the conditional probability of *D* given h likelihood. The posterior probability of classification can be calculated as (Alpcydn 2004) given in Equation (2) and (3)

$$P\left(\frac{hi}{d}\right) = \frac{P\left(\frac{D}{hi}\right)P(hi)}{P(D)} \quad (2)$$

$$\frac{P\left(\frac{D}{hi}\right)P(hi)}{\sum_{i=1}^{k} P\left(\frac{D}{hi}\right)P(hi)} \quad (3)$$

Based on the equation the formulation can be summarized as given in Equation 4.

$$posterior = \frac{prior\ x\ liklihood}{evidence} \quad (4)$$

E. Naive Bayes QoS Routing

This work a model that uses Naive Bayes classifier is developed that helps the source node to select a neighbour to transmit a packet based on the QoS requirement. The semantic structure of the model is shown in the following Figure1.The neighbouring node behaviour from the past history of delivered packets such as end to end delay, packet deliveryratio, number of packets delivered to destination, energyconsumption, and average delaywith varying queue

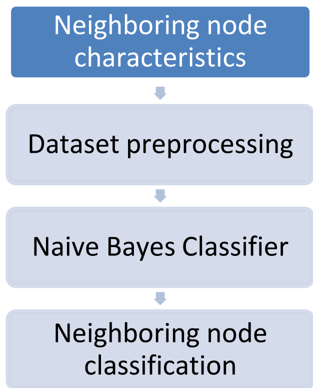

Figure 1 Pre-processing Data Flow

sizes are fed as input to the classifier. The data used for classification is created by running the simulation setup the one similar to the previous work [14]. The created data set is cycled through the classifier which learns the mapping relationship between the data attributes and the classes associated with it. The class here is real time and non-real-time.

Then out of the *k* neighbours near the source node, the classification algorithm picks out two sets of neighbours such as *l* and m. *l* set of neighbours corresponds to nodes suitable for real-time traffic and *m* set of neighbours suitable for non-real-time traffic. Every neighbour of a source can be reached to the destination. The total number of neighbours is directly proportional to the total number of path available to reach the destination. As the number of n path is divided into two sets of path suitable for real-time and non-real-time traffic, the classification algorithm helps to find the best suitable path in terms of minimizing end-to-end delay.

F. Traffic Allocation

Let α be an upper bound tolerance for real-time packet delivery requirement. The value of α can depend on the application and carefully set after examination of the time taken to react after an event occurred by the application. This work assumes the value of α and it is fixed. So now the nodes deliver the packet with less than the tolerance parameter $\alpha$are classified as the nodes suitable for real-time packet delivery and the rest is classified as nodes suitable for non-real time packets.

The work knows the priority of every packet received. The priority is assigned in the application layer by appending it in the header of the packet as an extra bit. Based on the priority information the source node allocates the traffic to neighbouring nodes. The classifier algorithm outputs the probability which is given in Equation (5),

$$p(neighbor)=0.1\geq 1 \quad (5)$$

The neighbour node that has the higher probability is more likely suitable for real-time traffic. We use a simple created dataset as given in table. Every node has its own set of data similar to the one given in Table 1. The data is extracted from all the packets forwarded by that particular node. The posterior probability is calculated and a frequency table is constructed. In the next step the frequency table is transformed into likelihood tables and then we use the Naive Bayesian equation to posterior probability. The class with the highest probability is used. The class in the present case is real –time or non-real-time.

The pre-processing of a data is very important and this is carried out before the data is fed into the classifier. This is to ensure that significant parameters are used for prediction and shall come up with optimal variables as input. Naïve Bayes classifier relies on counting techniques and thus the variables are scaled into categories. Further, the categorical variables are classified as nominal and ordinal. For example the end to end delay is categorized into different ranges as given in Table 1.

The data is extracted from all the packets forwarded by that particular node. The posterior probability is calculated and a frequency table is constructed.

In the next steps the frequencytable is transformed into likelihood tables and the Naive Bayesian equation to posterior probability is used. The class with the highest probability value is the outcome of the prediction. The class in the present case is real –time or non-real-time. The sample data set of n number packets is given in Table 2.The corresponding likelihood probabilities are calculated and given in Table 3.

G. Algorithm and Description

The algorithm for finding the next hop by the source node is given below. The input for the algorithm is the available neighbouring nodes within the transmission range of the source sensor node. The neighbouring nodes dataset are pre-processed according to the explanation given in the previous section. The source nodes discover the neighbouring nodes by using the neighbour discovery algorithm given below.

Table 1 Data Description and Measurement Level

Variable	**Description**	**Value**	**Level of measurement**
Etoe	end-to-end delay	0-10 = 1 10-20 = 2 20-30 = 3 30-40=4 40-50=5 50-60=6 60-70=7	ordinal

		70-80=8 80-90=9	
Pdr	Packet delivery ratio	0-0.2 =1 0.2-0.4=2 0.4-0.6=3 0.6-0.8=4 0.8-1=5	ordinal
arrate	Arrival rate	0-10 = 1 10-20 = 2 20-30 = 3 30-40=4 40-50=5 50-60=6 60-70=7 70-80=8 80-90=9	ordinal
ener	Energy consumption in J	0-0.01=1 0.01- 0.02=2 0.02- 0.03=3 0.03- 0.04=4 0.04- 0.05=5 0.05- 0.06=6	ordinal

Table 2 Sample data set

		etoe	*pdr*	*arate*	*ener*	*Class*
Node$_i$	*P_0*	1	2	9	6	Rea-time
	.					
	.					
	.					
	P_i	5	3	1	4	Non-real-time

Neighbor_Discovery : [The process is initiated by sink node**]**

1. **[**Initialize**]**

my_node_id←get_nodeid()

2. [Only sink node execute this step]

pkt.type←SINK_BROADCAST
[Set sink node id]
    init(pkt)
    pkt.hopcnt← 0
    pkt.sinkdist← 0
    pkt.dest←BROADCAST
    Broadcast (pkt)

3. [Each sensor node execute this step on receiving the pkt]

[updating neighbor list]
    neighbor.nodeid←pkt.srcid
    neighbor.x←pkt.x
    neighbor.y←pkt.y
    neighbor.hopcnt←pkt.hopcnt
if already transmitted the pkt
    return
else
    init(pkt)
    pkt.hopcnt++
    tmp←dist(pkt.x, pkt.y, pkt.sdist)
    pkt.sdist←tmp + pkt.snkdist
    broadcast (pkt)
end if

4. Terminate

return [end of algorithm]

Table 3 Likelihood table for all predictors

Liklihood	**P(Real time packets)**	**P(non real time packets)**
etoe	$P(1\|n_{rt})$, $P(2\|n_{rt})$, $P(3\|n_{rt})$ $P(4\|n_{rt})$, $P(5\|n_{rt})$, $P(6\|n_{rt})$ $P(7\|n_{rt})$, $P(8\|n_{rt})$, $P(9\|n_{rt})$	$P(1\|n_{nrt})$, $P(2\|n_{nrt})$, $P(3\|n_{nrt})$ $P(4\|n_{nrt})$, $P(5\|n_{nrt})$, $P(6\|n_{nrt})$ $P(7\|n_{nrt})$, $P(8\|n_{nrt})$, $P(9\|n_{nrt})$
Pdr	$P(1\|n_{rt})$, $P(2\|n_{rt})$, $P(3\|n_{rt})$ $P(4\|n_{rt})$, $P(5\|n_{rt})$	$P(1\|n_{nrt})$, $P(2\|n_{nrt})$, $P(3\|n_{nrt})$ $P(4\|n_{nrt})$, $P(5\|n_{nrt})$
Arate	$P(1\|n_{rt})$, $P(2\|n_{rt})$, $P(3\|n_{rt})$ $P(4\|n_{rt})$, $P(5\|n_{rt})$, $P(6\|n_{rt})$ $P(7\|n_{rt})$, $P(8\|n_{rt})$, $P(9\|n_{rt})$	$P(1\|n_{nrt})$, $P(2\|n_{nrt})$, $P(3\|n_{nrt})$ $P(4\|n_{nrt})$, $P(5\|n_{nrt})$, $P(6\|n_{nrt})$ $P(7\|n_{nrt})$, $P(8\|n_{nrt})$, $P(9\|n_{nrt})$
ener	$P(1\|n_{rt})$, $P(2\|n_{rt})$, $P(3\|n_{rt})$ $P(4\|n_{rt})$, $P(5\|n_{rt})$, $P(6\|n_{rt})$	$P(1\|n_{nrt})$, $P(2\|n_{nrt})$, $P(3\|n_{nrt})$ $P(4\|n_{nrt})$, $P(5\|n_{nrt})$, $P(6\|n_{nrt})$

The topology discovery algorithm is initiated by the sink. The process is initiated soon after the deployment of the sensor nodes. In step 1 the node id is initialized. In the next step 2, the sink node creates a sink flood type packet and sets its node id, x and y coordinates positions suing the function init. The packet is broadcasted with the type as broadcast. In step 3 the node updates its neighbouring list with the variable information from the packet. If the type of packet is not forwarded previously then the information present in the packet is replaced by its own information and forwarded to its neighbours.

As a result the source node knows the neighbouring nodes. On sensing an event by the source sensor invokes step 1. In step 1 the probability values for real-time and non-real-time deliveries of the packet are classified using the algorithm NB_Classifier. In step 2 for real-time packets the source node chooses the neighbour node that has the highest probability predicted by NB classifier. For transmitting non-real-time packets the source node chooses the neighbouring node with higher probability which has not been used for transmitting the packet in the current and the previous time slot.

Algorithm NB_based_QoS_Approach
Input :likelihood table values of all the predictors, The Qos predictors tuple {*pre_etod, pre_pdr, pre_arate, pre_adelay*}

Output: P(neighbor|RT) and P(neighbor|NRT)

1. **Initialize: [**pick out the probabilities from the likelihood table for the given set of conditions]

   etod← likelihood(*pre_etod*)
   pdr← likelihood(*pre_pdr*)
   arate← likelihood(*pre_arate*)
   adelay←liklihood(*pre_adelay*)

2. [The source node execute for every neighbors]

$$P(neighbor)_{rt} = \frac{P(RT)\, P\left(\frac{etod}{RT}\right) P\left(\frac{pdr}{RT}\right) P\left(\frac{Arate}{RT}\right) P\left(\frac{Adelay}{RT}\right)}{P(etod)P(pdr)P(Arate)P(Adelay)}$$

$$P(neighbor)_{nrt} = \frac{P(RT)\, P\left(\frac{etod}{NRT}\right) P\left(\frac{pdr}{NRT}\right) P\left(\frac{Arate}{NRT}\right) P\left(\frac{Adelay}{NRT}\right)}{P(etod)P(pdr)P(Arate)P(Adelay)}$$

   return(*P*(*neighbor*)$_{rt}$, *P*(*neighbor*)$_{nrt}$**)**

3. [Terminate]

End of the algorithm

The algorithm for NB_based_QoS Approach is based on Naïve Bayes classification algorithm. The input to the algorithm is the tuple {*pre_etod, pre_pdr, pre_arate, pre_adelay*}, where the values are the QoS requirement specification set by the user. The QoS requirement specification throughout the thesis is based on the assumption and in real-time the requirements can be selected depending on the application requirement and carefully tuned based on the achievable performance. In the step 1 the algorithm picks the corresponding probability for the predictor's value from the likelihood table. The input is fed into the classifier and the probability values for real time traffic and non-real time traffic are returned to the caller.

IV. Results and Discussion

The performance of the scheme is evaluated to determine the effectiveness of the system through simulation experiment. This section describes the simulation experiment and does a comparative study of Multi-constraint Multi-Path (MCMP) routing protocol and energy efficient QoS aware routing protocol (EQSR) both real time traffic (EQSR-RT) and non-real time traffic(EQSR-NRT). The authors have used Castalia [15] network simulator based on OmNet++[16] for simulation.

The simulation experiment consists of 300 nodes deployed in a 500 X 500 m. The sink node is located in the corner of the sensor field. The performance is investigated in a multi-hop network topology. The metrics used in the evaluation are the energy consumption, delivery ratio and average delay. The impact of packets generation rate and node failure probabilities is studied.

A. Average End-to-End delay

The average delay of NB-QoS EQSR-RT, EQSR-Enhanced are shown in Figure 2. The packet arrival rate is varied in increasing 10 numbers of packets and the performance is measured. The NB-QoS mechanism in Figure 2 shows the delay for all the real and non-real traffic. From the Figure 2 it is clearly inferred that as the arrival rate of the packet increases the end-to-end delay also increases due to the increase in volume of packets. For any real-time applications the delay in reaching the sink is considered highly critical because, any additional delay apart from reasonable in transmitting a packet will further delay the corrective actions need to be taken by the user of the application.

B. Packet delivery ratio

The packet delivery ratio is another critical requirement for the sensor networks. Any deviation from considerable amount of packet delivery ratio will increase the failure probability of the application. The packet delivery ratio is the measure of number of packets successfully delivered to the destination. Figure3 is the packet delivery ratio of the NB-QoS approach. The Figure 3 shows the comparison with

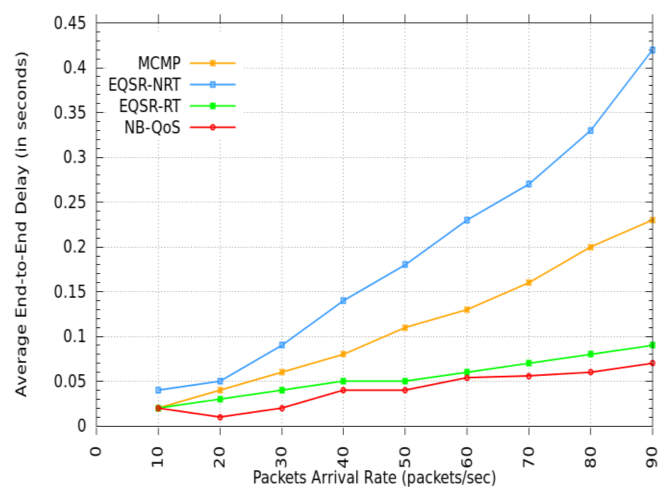

Figure 2 End to End delay

other techniques such as MCMP, EQSR-RT and EQSR-NRT. As the packet arrival rate increases the packet delivery ratio of NB-QoS based approach drops gradually. This is due to large number of packets that are corrupted due to noise and collisions. But when NB-QoS is compared to other techniques such as EQSR and MCMP the packet delivery ratio is more and therefore it is concluded that NB-QoS outperforms the compared techniques.

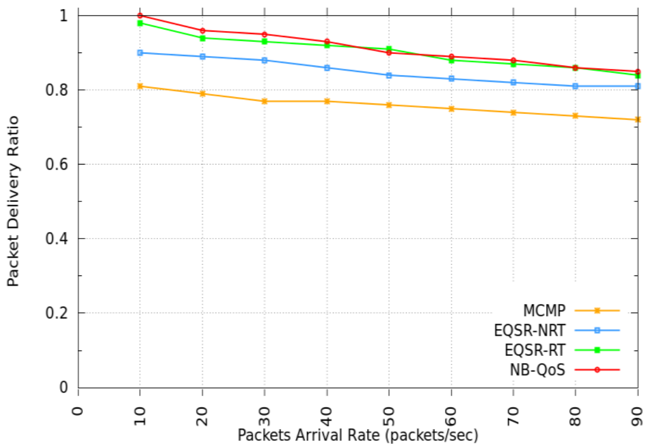

Figure 3 Packet delivery ratios of NB-QoS

C. Energy Consumption

Figure 4 shows the energy consumption of the NB-QoS approach and the existing techniques such as EQSR-NRT and EQSR-RT. The energy consumption is low when compared to other techniques when the packet arrival rate is 10 and as the arrival rate increases from 10 to 20 the energy is dropped when compared to existing approaches. Further on increasing the packet arrival rate the energy consumption is dropped when compared to the existing approaches. The energy consumption increases steadily as the packet arrival rate increases due to the large volume of packets reporting to the sink. Therefore, from this inference it is concluded that NB-QoS scheme is well suited for applications that report the events to sink frequently.

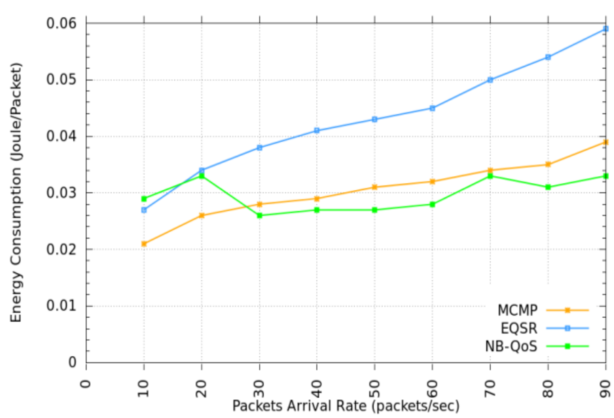

Figure 4 Energy consumption of NB-QoS

D. Node Failure Probability

The node failure probabilities and the corresponding delay are shown in Figure 5. From the figure it is inferred that as the node failure probability increases the end-to-end delay also increases gradually due to the dis-connectivity of routing path to sink. When compared to other approaches the delay is minimal and as the node failure probability increases further the delay is similar to EQSR-RT. From the Figure 5, it is clearly inferred that NB-QoS successfully differentiates the real-time traffic and non-real-time traffic and thus the scheme reduces the end-to-end delay with increase in node failure probabilities.

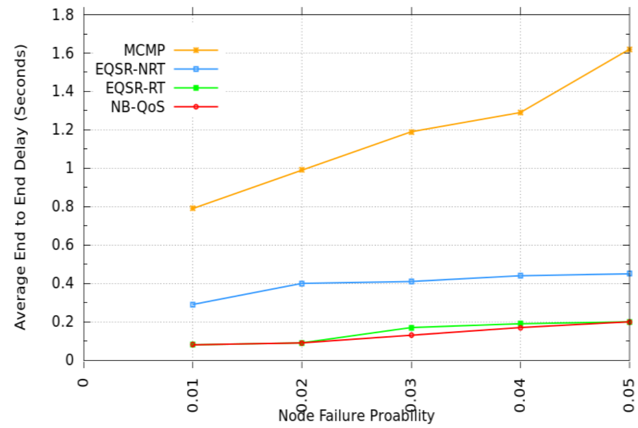

Figure 5 Node failure probabilities of NB-QoS

Figure 6 shows the results of the average packet delivery ratio and the node failure probabilities. The average packet delivery ratio is slightly lower when the node failure probability is 0.01 when compared to EQSR-RT. But the delivery ratio is significantly higher when compared to MCMP and the EQSR-NRT approaches.

As the node failure increases from 001 to 0.02 the delivery ratio also increases when compared to EQSR-RT, EQSR-NRT and MCMP protocols and continues to increase the delivery ratio for the remaining node failure probabilities. From the Figure 6 it is clearly inferred that the node failure probability is not affected too much when compared to EQSR-RT, EQSR-NRT and MCMP approaches. Therefore it is inferred that the scheme NB-QoS outperforms all the other approaches and is able to increase the quality of packet delivery ratio.

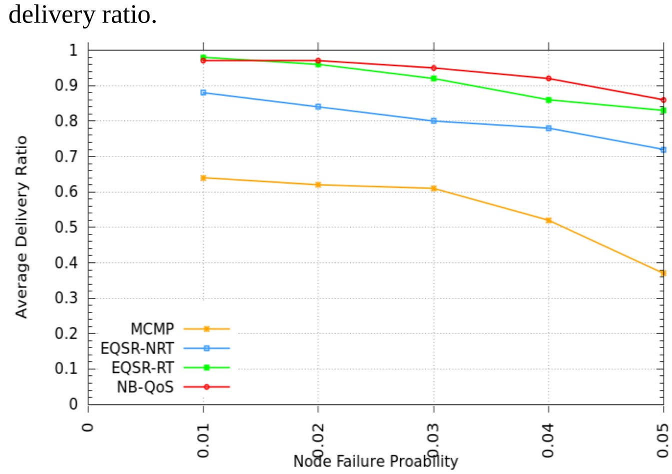

Figure 6 Node failure probabilities and delivery ratio of NB-QoS

V. CONCLUSION AND FUTURE SCOPE

In this paper, a newer scheme based on Naïve Bayesian classifier to provide QoS in sensor network is presented. The protocol uses multi-path paradigm together with routing techniques to provide QoS. The scheme uses the delay, packet delivery ratio and energy of the previously transmitted packets to select the next hop using NB-QoS algorithm. Through simulation the NB-QoS is evaluated and the various performances are studied under different conditions. The limitation of the scheme is it does not able to deliver all the packets for less number of nodes. As a part of future work it is intended to study and analyse the impact of memory and the network buffers along with various path length on the performance metrics.

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