Network Selection for Remote Healthcare Systems through Mapping between Clinical and Network Parameter

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Abstract. The paper presents fuzzy based approach to select best suited network for remote healthcare services. A direct mapping between clinical parameters and corresponding QoS network parameters is done. The paper proposes an application independent integrated system where stage of the disease is identified based on the fuzzified clinical parametric values which are critical for that disease. Based on critical nature of the disease i.e. stage of disease, the requirements of network QoS are defined in linguistic terms. This eliminates strict sense condition on any specific network and selects most suited network out of all available networks. The objective is to avoid denial of service in case of unavailability of a network with high QoS values and also to conserve resources in case the patient is in normal condition medically. A simulation study has been presented to verify the selection of the network based on stage of disease.

Keywords: Index Terms: heterogeneous networks, network selection, remote healthcare, fuzzy logic, QoS.

1 Introduction

Availability of healthcare services to the population in every corner has undoubtedly become one of the priorities for Health Organizations. This requirement is more challenging for the Low Income Countries (LIC) and Lower Middle income countries (LMIC) [1]. Population in these countries is predominantly rural and distributed across distant geographically diverse locations in countries like India. Despite several advances and developments in the medical field, its access is restricted to some privileged section of the society residing in urban areas of falling under high income group. The hierarchical structure of healthcare facilities further restricts the access to specialty health services to the rural population.

The fast evolving information and communication technology supported by increasing use of mobile devices has resulted in the development of e-health and m-health services. Several such remote healthcare systems have been developed and tested [2 – 4]. However, these systems suffer from limitation of their dependence on a particular type of network. Their use is therefore restricted to the areas falling under

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the coverage zone of that network. Further, demand for high level of Quality of Service by these mission critical services still restricts its use in the remote areas. The concept of integration of technologies and user level customization introduced by 4G systems will provide a solution to these problems. The objective is to provide remote healthcare service irrespective of the type of communication link available. Specifying network requirements and selecting optimum network remains an open issue for such systems.

In this paper, we present a fuzzy based approach to generate network requirements in terms of QoS parameters based on the physiological data generated by data acquisition devices i.e. body sensors. There are sensor based systems available which acquire clinical parameters from human body and transmit them through a compatible communication system [5]. However, in the era of heterogeneous/4G systems, there are reconfigurable and customizable devices with ability to communication through more than one type of networks or communication links [6, 7]. Fig. 1 presents a remote healthcare system based on such devices and body sensors. Selecting optimum network out of several available network is still an open issue and under research. We intend to use such devices for the mission critical application of remote healthcare services. Therefore, a direct mapping between clinical parameters and network QoS parameters for network selection has been presented in this paper. To further keep the approach generalized and applicable to several diverse medical situations, fuzzification of clinical parameters has been done before it can be used for generating network requirements.

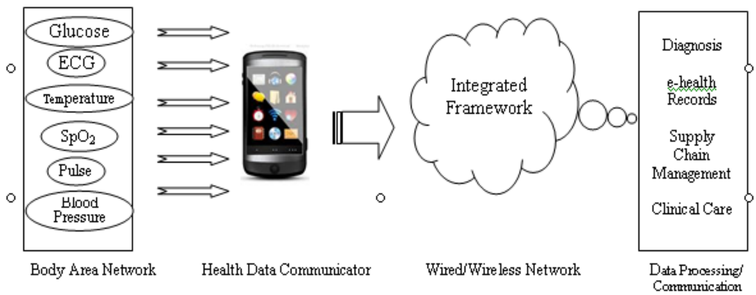

Fig. 1. Remote healthcare system based on mobile devices communicating through heterogeneous networks. Body sensors monitoring various clinical parameters provide necessary information to frame selection criterion at the communicator device.

Rest of the paper is organized as follows. Section II presents fuzzy functions for some of the commonly used clinical parameters. A mapping scheme between fuzzy clinical and network QoS parameters is introduced in section III. A clinical case study has been taken for this purpose. Section IV concludes the paper with summarizing contribution of the work and its future scope.

2 Fuzzy Functions for Clinical Parameters

Since our focus is on healthcare services the paper proposes a network selection scheme considering QoS parameters required for the transmission of physiological information being monitored. The device needs to process the data received from the body sensors and suggest the condition of the patient and decide the seriousness of the application. Based on this decision, QoS requirements are generated to select the optimum network to transmit this data. We propose a fuzzy logic system to process the patient's physiological parameters. In spite of this, human body is so complex that it would be impossible to cover every single measurable body parameter. Some of the commonly used vital signs of human body have been considered in this paper. Table 1 presents a list of such vital signs along with their normal range values. The range of values representing different medical conditions used in this paper is based on inputs received from various medical practitioners whose identities have not been disclosed here. For each of these parameters, fuzzy functions F(parameter) are defined in linguistic terms.

Table 1. Body parameters being monitored alongwith their prescribed normal range of values

Parameter	Normal range
Body Temperature	36.5 – 37.5 ^{o}C
Blood Pressure (systolic)	120 mmHg
Blood Pressure (diastolic)	80 mmHg
Blood Sugar	100 mg/dL
Blood Oxygen Level	85 – 100 mmHg
Oxygen Saturation	97 – 100 %
Heart or Pulse Rate	72 (daily average)

Body Temperature. Most of the medical ailments in human body result in variation of the body temperature. It is, therefore a most commonly examined physiological parameter. In our proposed work, we have defined this vital sign using fuzzy logic having five membership functions. Temperature range for hypothermia and hyperthermia has been considered to select the lower and upper limit.

F(temperature) = {LowCritical, LowMarginl, Normal, HighMarginal, High Critical}

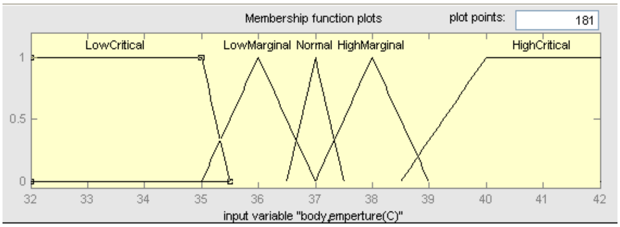

Fig. 2. Membership functions for body temperature

Heart Rate or Pulse Rate. A daily average value of 72 beats per minute (bpm) is considered to be normal for an average human body. Neglecting any irregular activity, the heart beats at a rate 30% faster during day time as compared to night while sleeping. This makes overall range for the entire day to 55 – 100 bpm. It is to be noted that fuzzy equivalent used for this parameter in this paper is for the average values.

F(pulse) = {LowCritical, LowMarginl, Normal, HighMarginal, High Critical}

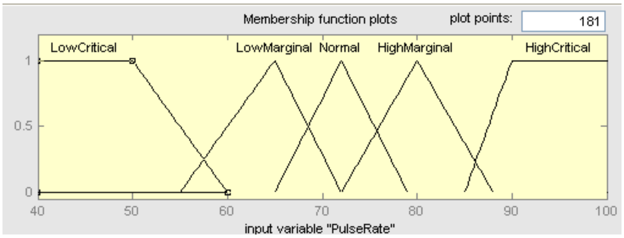

Fig. 3. Membership functions for heart rate or pulse rate

Many more such representations can be obtained based on different conditions of the patient such as during physical activity, during rest and so on. A set of If – Then statements can be used to select the appropriate condition among the set of available conditions.

Blood Pressure (Systolic and Diastolic): It is a parameter which, compared to the above two parameters, shows irregular pattern if observed for entire day. The mean blood pressure for an average healthy adult human being is 120 mmHg for systolic and 80 mmHg for diastolic but varies 20mmHg for systolic and 10 mmHg for diastolic above and below during different activities throughout the day. The fuzzy equivalent of these two parameters involves five membership functions each.

F(BP-sys) = {LowCritical, LowMarginl, Normal, HighMarginal, High Critical}

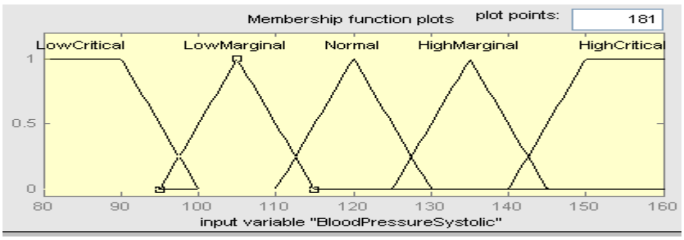

Fig. 4. Membership functions for blood pressure – systolic

F(BP-dia) = {LowCritical, LowMarginl, Normal, HighMarginal, High Critical}

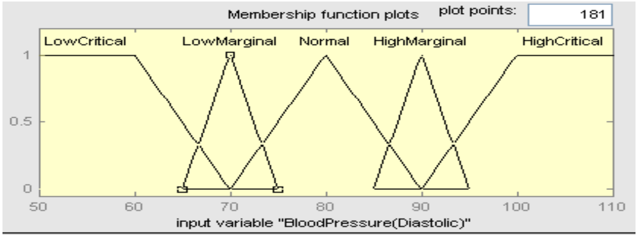

Fig. 5. Membership functions for blood pressure -diastolic

Blood Sugar: Blood sugar or blood glucose level in human blood is measured as mg/deciliter or mill moles per liter. 1 mmol/L is equivalent to 18 mg/dL. Its normal value is 100 mg/dL when fasting and can go up to 140 within one hour of having food. For diabetic patients, it can be as high as 400 or above and can drop down to 70 or less. High or low blood sugar level can often lead to various complications like coma or death. A five level fuzzy function has been used for this parameter also.

F(sugar) = {LowCritical, LowMarginl, Normal,HighMarginal, High Critical}

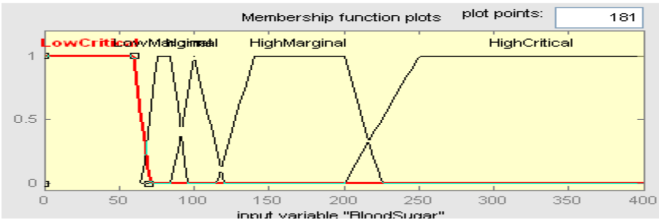

Fig. 6. Membership functions for blood sugar level

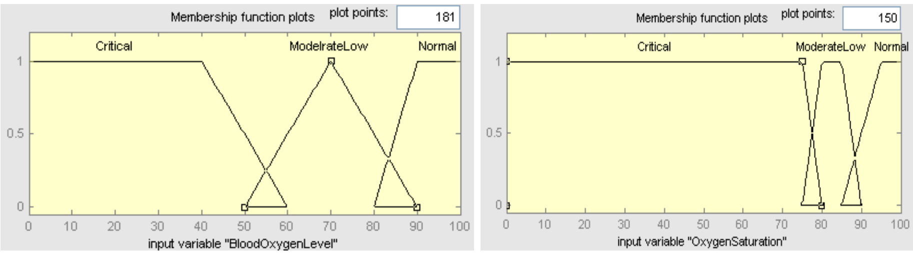

Fig. 7. Membership functions for blood oxygen level and oxygen saturation

Blood Oxygen Saturation. Ability of the lungs to supply oxygen to the blood is measured through the blood oxygen level. It is used to evaluate the oxygenation and saturation of haemoglobin in the blood. There are three parameters involved – (a) partial oxygen pressure (mmHg) in arterial blood (PaO_2 in Pulmonary Capillary or PAO_2 in Alveolus, differing by 10 mmHg), (b) direct measurement of the percentage of blood oxygen saturation level (SaO_2) and (c) indirect measurement of the percentage of blood oxygen saturation level (SpO_2). First term refers to dissolved oxygen and the normal value is 90 – 100 mmHg. A level below 80 mmHg is the beginning of moderate hypoxia and its drop to 40 results in critical hypoxia. The second and third terms are for oxygen bound to hemoglobin and the required level of saturation is 97 – 98 %. Decrease in the level of all these parameters represents medical ailment.

Two fuzzy variables namely blood oxygen level and oxygen saturation have been defined each having three membership functions as shown in fig. 7.

F(blood-oxy) = {Critical, ModerateLow, Normal}
F(lood-sat) = {Critical, ModerateLow, Normal}

3 Mapping Clinical Parameters with Network Parameters

The clinical data acquired through body sensors is used for several healthcare applications e.g. diagnosis and post hospital monitoring. There are two fold objectives of this remote monitoring system.

1. To keep a regular/time based record of the patient's condition without getting admitted to a hospital or healthcare centre.
2. To generate alert signal when one or more clinical parameters crosses the predefined upper or lower threshold limit.

The objective of this paper is to propose a monitoring system which does not depend on any specific communication technology but works with the most suitable of all the available links. We, therefore, make some elementary clinical inference about state of

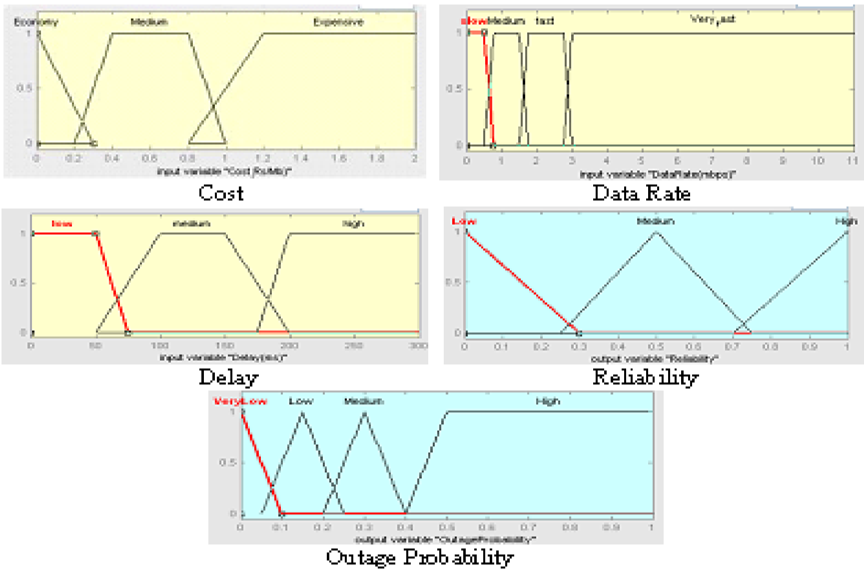

Fig. 8. Fuzzy functions for QoS parameters in linguistic terms

the patient being monitored to generate QoS requirements for efficient transmission of the sensor's output data. Depending on the disease for which the patient is being monitored, a set of fuzzy rules are written which give a set of QoS parameters as output variables. Five such network QoS parameters have been used in this paper viz. Cost of network usage, Data Rate, End-to-End Delay, Reliability (in terms of Packet Loss and Bit Error Rate-BER) and Outage Probability. Since the values of these parameters for any available networks may depend on a large number of factors and thus vary from place to place, it is not justifiable to define the QoS requirements in the form of crisp values. We, therefore generate QoS requirements in linguistic terms which are then represented by fuzzy variables as shown in fig. 8.

Corresponding fuzzy functions G(parameter) are defined as:

- G(cost) = {Economy, Medium, Expensive}
- G(data-rate) = {Slow, Medium, Fast, VeryFast}
- G(delay) = {Low, Medium, High}
- G(reliability) = {Low, Medium, High}
- G(outage-prob) = {VeryLow, Low, Medium, High}

3.1 Clinical Case Study - Diabeters

Diabetes, a common and globally widespread disease, has been taken as a clinical case to study the proposed network selection scheme. Six clinical parameters introduced in section II are generally monitored for diabetic patients. A fuzzy rule base is defined taking clinical parameters as input variables and network parameters as output variables. Based on deviation in the observed values of these parameters from their normal values, we define four different stages of the patient viz. Normal (Nm), Marginally High (MH), Very High (VH) and Critical (Cr). Each of these stages generates a different set of QoS requirements in terms of network parameters defined in fuzzy terms earlier in this section. Table 2 gives the lookup table between four disease stages and corresponding QoS requirements. A total of 70 fuzzy rules were created. 15 of them represent Normal Stage. Marginally High and Very High stages are represented by 20 rules each. Critical stage results from outcome of 15 rules. The proposed scheme was tested on the pre-recorded data of 50 diabetic patients.

Fig. 9 present the direct fuzzy-to-fuzzy mapping system between clinical and network QoS parameters. Mamdani rule base model has been used to draw fuzzy

Table 2. QoS requirements based on clinical stage of the patient

QoS Parameters	Fuzzy Network QoS Values for Different Disease Stages			
	Normal	**Marginally High**	**Very High**	**Critical**
Cost	Economy	Medium	--	--
Data rate	Medium	Medium	Fast	VeryFast
Delay	High	Medium	Low	Low
Reliability	Medium	Medium	High	High
Outage Probability	High	Medium	Low	VeryLow

inferences. Functions F(parameter) defined for Clinical parameters have been used as input fuzzy functions. The output is available in the form of functions G(parameters) defined for network parameters.

Fig. 10 presents graphical view of QoS requirements derived by using proposed scheme on sample data. Samples have been taken so as to include all the four stages of disease defined in this case study. For simple representation, QoS levels have been shown by using numbers. Table 3 gives the linguistic terms corresponding to each level for all the five network parameters used as output fuzzy variables.

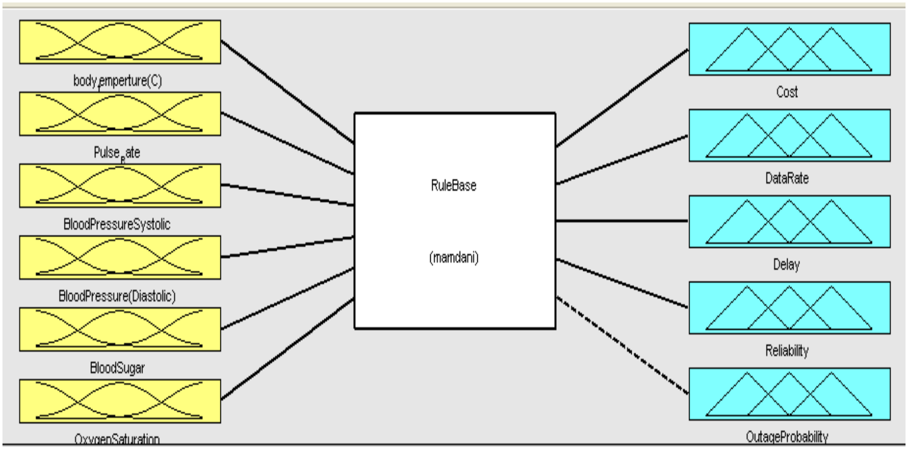

Fig. 9. Fuzzy based mapping system between clinical and network QoS parameters

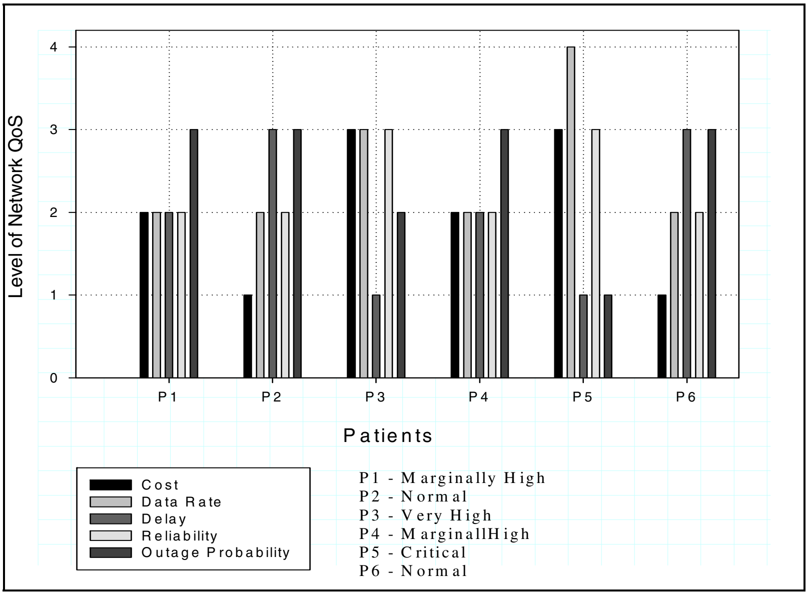

Fig. 10. Mapped QoS level requirements for patients from sample data

4 Testing the Network Selection

To verify the proposed scheme, a sample heterogeneous test environment with four different networks (shown in fig. 11) has been simulated. The QoS values for these test networks were adjusted according to the networks available in the author's research place. Four patient's nodes correspond to the health data communicators shown in fig. 1, each having four network interfaces compatible with four test networks.

Table 3. QoS levels in linguistic terms corresponding to numeric levels used in fig. 10

QoS Parameters	Linguistic Terms for QoS Levels in Fig. 11			
	Level 1	**Level 2**	**Level 3**	**Level 4**
Cost	Economy	Medium	Expensive	--
Data rate	Slow	Medium	Fast	Very Fast
Delay	Low	Medium	High	--
Reliability	Low	Medium	High	--
Outage Probability	Very Low	Low	Medium	High

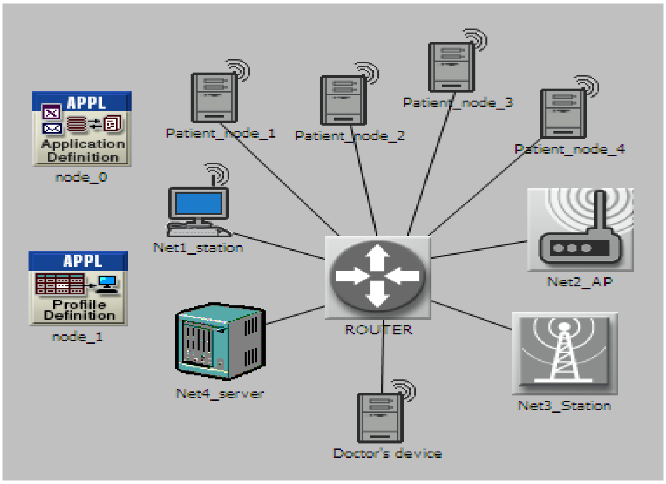

Fig. 11. Simulation setup with four test networks, four patient devices as source, and one medical practitioner's device as destination

Table 4. four patients with different disease stages and their corresponding selected networks as a result of simulation

Patient No.	Disease Stage	Selected Network
1	Marginally High	**N2**
2	Normal	N1
3	Marginally Hgh	N2
4	Very High	N3

Clinical parameter values for four different diabetic cases falling under disease stages – Normal, Marginally High and Very High were used to generate the network requirements in terms of QoS parameter (Data for Critical stages was not available and hence not simulated). A local medical practitioner was consulted for this purpose whose identity has been kept hidden on request. Network selection scheme introduced in [8] was used for this purpose. It was verified after simulation that patients falling under different stages of the disease used different networks to transmit the clinical data recorded by the body sensors. Fig. 12 and table 4 give the simulated results.

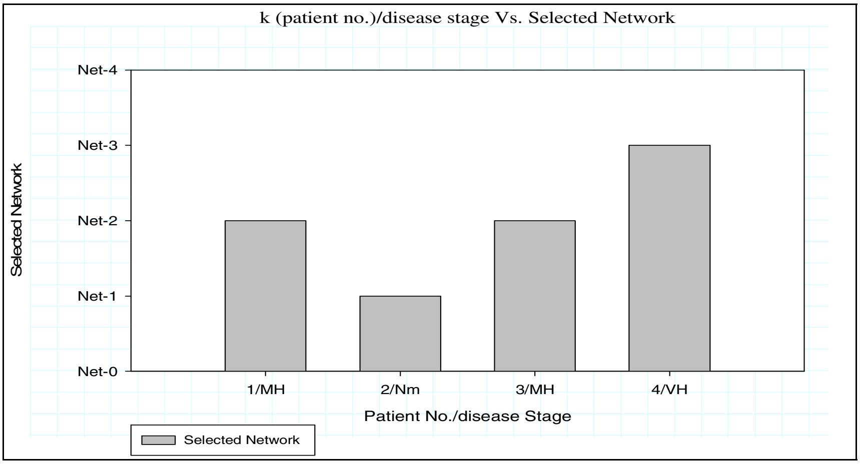

Fig. 12. Selected Network for patients at different disease stages

5 Conclusion

The Proposed work presents a fuzzy based approach to map the stage of patient's disease with the selection of an optimum network for remote monitoring services. The selection of right network will ensure the transfer of vital clinical parameters to the control centre irrespective of the location of the patient and availability of high performance network. The values of clinical parameters have been fuzzified and mapped into a set of linguistic network QoS levels as desired QoS requirements. These requirements can be used as input to any suitable network selection algorithm. The simulation study presents a roadmap towards a complete integrated remote healthcare system.

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