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An Information Theoretic Approach for the Development of a Framework for Improving Communication Reliability in a Mobile Network

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Abstract— Low connectivity in mobile networks is a perennial problem. Too many challenges are faced by network designers and service providers including development and deployment of network infrastructure that must meet QoS (Quality of Service) guarantee. Many a times there are geographical hindrances, such as due to mountains and trees, and many a times in cities obstruction, fading and signal attenuation occur because of buildings and other mobile and fixed infrastructure. We present our findings and ideas regarding an on-going research on development of a framework that can be used in a low-connectivity mobile network for enabling communication among nodes. To enable communication in low connectivity sites, our proposed framework uses a cooperative approach described in later sections.in this paper. Moreover, the framework makes the network inherently secure as well. In this paper we present these ideas along with assumptions and an example scenario where this framework is has shown promising results. Simulation results have shown strong correlation with our proposed theoretical ideas.

Keywords—Wireless, Communication, mobile, reliability, information theory

I. INTRODUCTION

I There are many challenges in mobile networks. Mobility makes the channel highly dynamic and unpredictable [1]. Apart from dynamic nature other issues includes special requirement that must meet such as availability of communication infrastructure, security mechanisms for secure communication etc. Although Ad-hoc networks have been suggested for many of such cases, it has its own drawbacks and limitation. One specific limitation in ZRP (Zone Routing Protocol) in Ad-hoc network routing is lack of security measures because there is no central monitoring authority to ensure secure communication among nodes [2]. Due to these and other reasons low connectivity and frequent black outs in many areas are common. Tackling such network failure is most foremost priority and responsibility of a network designer and service provider. More so because they have to fulfill the QoS guarantee. Often fulfillment of a “Five Nine” availability criteria (i.e. average availability of 99.999%) is expected. For "Five Nine" availability it means a maximum allowed yearly downtime of 5.26 minutes [3]. This availability has to be maintained because the service provider is obliged to fulfill QoS guarantee.

In this paper we demonstrate our proposed Framework that can help us develop a more reliable wireless communication network. This would help us improve reliability in communication across areas where there is very low connectivity. We have chosen a specific scenario for demonstration of our framework, but we argue that our framework can be extended to many other cases, and this is the future scope of this work.

The rest of the paper has been organized as follows: Section II lists down various assumptions and scenarios where our framework is applicable. The same section presents relevant mathematical concepts of Information theory that model our assumptions. Section III presents idea of our framework in detail. Section IV briefly discusses the role of data compression. Section V presents process flow. Information ranking is one of the most important steps in our proposed framework. We present this idea in Section VI. Section VII discusses our simulation approach for establishing the usefulness and correctness of the framework. Results have been discussed in Section VIII. Finally, Section IX discusses important conclusions drawn so far from this research.

II. SCENARIOS & ASSUMPTIONS

We describe the scenario considering around which, we have developed this framework. Consider the following situations and assumptions:

A. A large number of employees of a company work on a project on-site. The connectivity between Head office and the project site is poor due to lack of communication infrastructure and other reasons. Assume that at any point of time a large portion of the information required by employees at the project site is common.

B. This is another situation and it relates to military. Consider a military regiment or company at a particular area, which has to communicate with a central monitoring authority. The connectivity between central monitoring authority and the regiments location is poor due to lack of communication infrastructure and other reasons. Assume that at any point of time a large portion of the information required by regiment at the project site is common.

C. Consider an example of telemedicine. The doctor at the main hospital in City needs to communicate with doctors and patients at a remote village. The connectivity between main hospital and the village hospital is poor due to lack of communication infrastructure and other reasons. Assume that at any point of time a large portion of the information required by doctors at the village hospital is common.

The assumptions made above can be expressed mathematically using information theory concept of Mutual Information[4]:

$$I(X;Y) = \sum_{y\in Y} \sum_{x\in X} p(x,y) \log\big(p(x,y)/p(x)p(y)\big) \ldots. (1)$$

Where p(x, y) is the joint probability function of X and Y, and p(x) and p(y) are the marginal probability distribution functions of X and Y respectively. In short, mutual information actually measures the information that X and Y have in common. It gives a measure of uncertainty of one with knowledge of other.

If the two nodes at the project sites share no common information then knowing X does not give any information about Y and vice versa, so their mutual information is zero.
This can be seen by using (1) above and substituting appropriate values:

$$I(X;Y) = \log\big(p(x,y)/p(x)p(y)\big) = \log 1 = 0 \quad \ldots\ldots\ldots\ldots (2)$$

The information theory gives us tools that are necessary to measure information and design our communication network in such a way that meets QoS guarantee.
We assume that mutual information among the nodes, i.e. for all X, Y, the I (X, Y) is a high value. Which in simple terms means most of the information at the project site is common among the nodes.

There could be many such scenarios though we have cited only three. Our framework is designed around these situations and assumptions.

In the following sections we describe our proposed framework in detail considering the above assumptions.

III. FRAMEWORK IDEA

Our approach is based on a kind of cooperation that is agreed among the mobile nodes situated on-site. Our proposed framework helps us develop protocols that takes into considerations this fact. An example protocol works as described below:

As we have already stated in previous section most of the information is often common among the users/employees working onsite. So, the idea is to develop a mechanism which enable them to cooperatively exchange this common information on-site. This cooperative information exchange at the project site can be accomplished by various short-range communication modes such as BT, Wi-Fi, as the mobile nodes in such situations are expected to be in close proximity.

The Head office then need to take care of that small percentage of user-specific data or employee-specific data which is not common. This user-specific data can be communicated through low bandwidth global communication media such as SMS, and/or a combination of SMS and GPRS (Low speed internet connection), for example.

IV. DATA COMPRESSION

Although we have not yet started working on data compression mechanism for this framework, we propose to compress data using least possible bits at the server, since on-site there are large number of helpful-neighboring-MS (mobile stations, which we shall describe in next section), who will verify the integrity of data and help recover any lost data [4]. This would make the system fault-tolerant.

Video and image can be switched to low resolution mode by using less no. of DCT (Discrete Cosine Transform) components during MPEG encoding, which puts less load on the mobile stations or nodes while decoding the video. Real time decoding in low bandwidth can thus be made possible [5]!
Historical data and analytics (done on server or on MS or on helpful neighboring MSs) could help decide the ranking of information during low-bandwidth mode operation [6]. Ranking has been discussed in subsequent sections.

In this work we have not focussed on security issues in Ad-hoc networks. Moreover, security is now evolving as a bigger challenge since now everything is getting connected, thanks to Internet-of-things. The authors in [7-8] have presented a detailed survey in these are related areas.

V. PROCESS FLOW

The process flow is shown in the following chart:

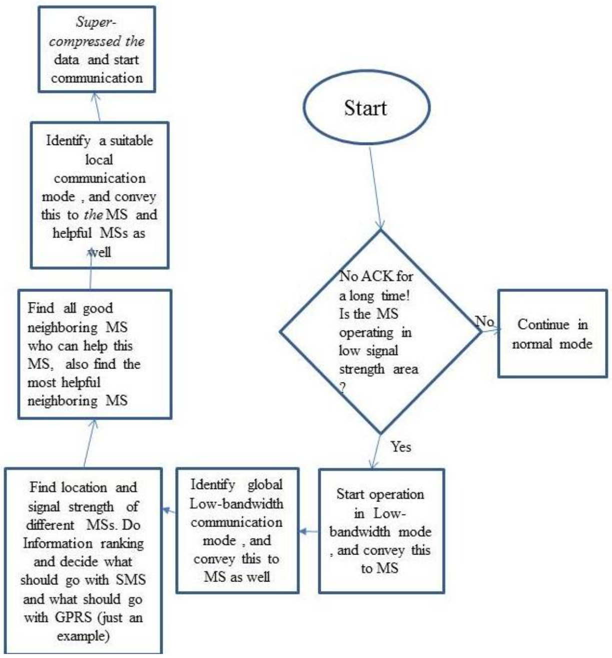

Figure 1. Framework process Flow chart

For the purpose of explanation assume that MS6 need some information, and we show here how this information is conveyed in a low bandwidth mode. We show this under the assumption described above in terms of (1).

The process starts when the server receives no response form the Mobile Station (MS) or nodes for predefined period of time. If the response is coming as expected the server site and the project site work in normal mode. But in case there is no acknowledgement, the framework forces the system to work in Low-Bandwidth Mode. Once the network operation is switched to Low bandwidth mode, the server at the Head office starts making a list of participating nodes or MS and decides communication medium for each MS. The communication media can also be SMS or GPRS. Which Information is sent by which media is also decided.

As shown in the flow chart, server identifies a list of neighbouring nodes or MSs who can help MS6. It also finds most helpful neighbour of MS6.

The idea is that these helpful; MSs have information which is required by MS6, so these helpful MSs will provide this information in the local network at the project site. That is why we say this is a cooperative approach where each node cooperatively helps achieve the successful communication, avoiding as much global communication as possible, which is more prone to fail as compared to the local shared short-range communication.

Then the communication link among these helpful nodes and MS6 is decided, which can be any of the short-range communication technologies. Before communication starts, a security layer comes into action which does encryption job. Also, what information is required by MS6 is instructed to all the other helpful neighbouring MS. This shared data is partial data which has no meaning on its own, so even if a security breach happens, an eavesdropper only gets a portion of some data which is of no meaning in itself. Therefore, this system is inherently secure.

VI. INFORMATION RANKING

Once the server knows that the mobile is being used in low signal strength area (for example by signal strength received by AT commands), it makes smaller sub-packets from the main packet, and gives it a rank based on how important it is. Mobile phone will also start working in low-bandwidth mode. Thus, this solution will adapt dynamically based on whether it is being used in low signal strength area or good signal strength area.

We show this ranking in the Fig. 2. below.

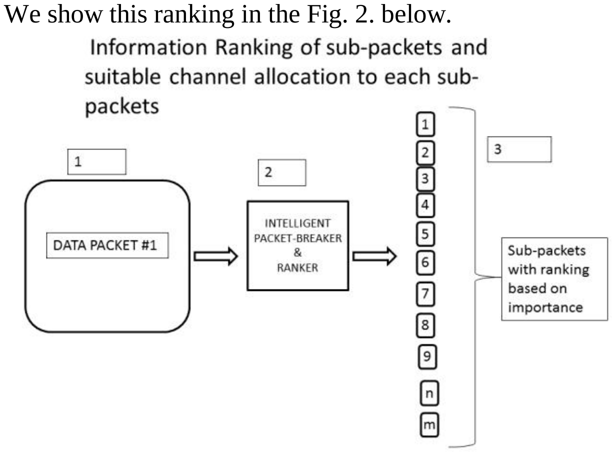

Figure 2: Information ranking

Each sub-packet is allocated a channel and mode of communication based on ranking. For example

Sub-Packet#3 is sent through SMS channel, while Sub-Packet#4 is allocated normal low speed internet communication, (as an example) since sub-packet #3 is more important than #4. Based on the above discussions we can say that most helpful neighbour is one who has maximum amount of high ranking & relevant sub-packets AND is nearest to MS 6. The server already has this info.

We now describe this concept with the following series of figures, which depicts how we limit this global communication between project-site and head office, and do more local short-range communication:

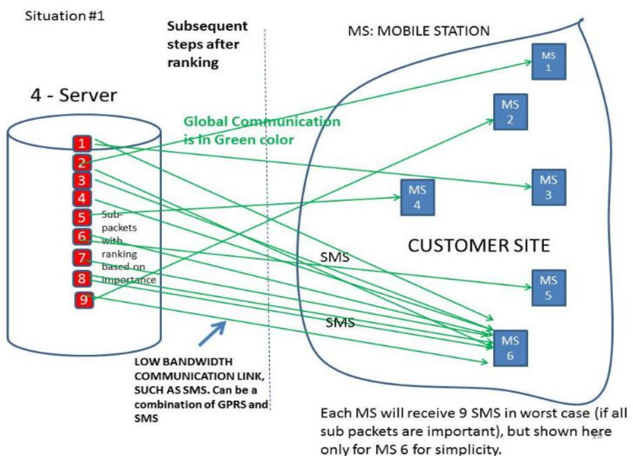

Figure 3. Example showing framework operation and information flow

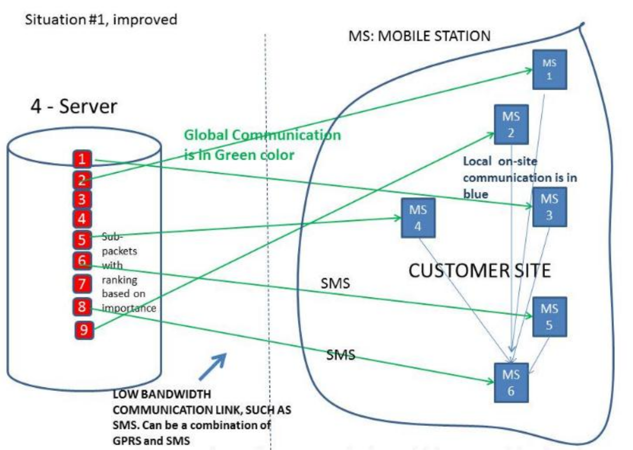

Figure 4. Improved situation by restricting global communication

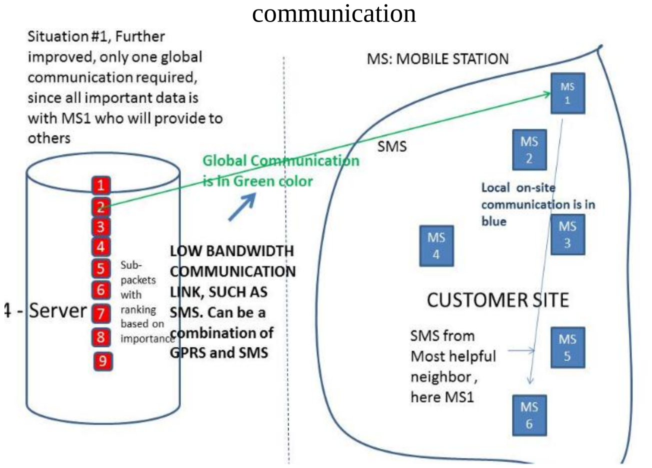

Figure 5. Situation shown in Figure 4 further improved

VII. SIMULATION APPROACH

How do we prove that our approach is actually working in a real scenario and what is its validity? To answer such questions, we now provide a methodology for simulating our ideas and we present simulation results in terms certain graphs which we believe substantiate our arguments.

The following steps explain how we simulated the process in our proposed framework:

1- Generate random symbols using alphanumeric Alphabets. Each symbol represents a piece of information. Also, as we assume that Mutual Information is high as shown in (1), we make sure that the generated data is highly correlated. Many libraries are available for generating correlated data.

2- We need to know the probability that a requested piece of information is made available to MS6 (referring to the discussions above) by its neighbouring helpful nodes, within a prescribed minimum time interval.

3- We can also estimate search time for a requested item among the generated symbols, to see how quickly we are able to locate it for a given Mutual Information or degree of correlation. The probability that the requested information is made available within prescribed time is made available will be then proportional to this search time.

4- We can then plot a graph between Search times Vs. Size of Symbol space generated (depicting number of helpful neighbours) for a given value of Mutual Information or degree of correlation. This graph will show for what value of degree of correlation how is the search time varying with symbol space size. This graph further explains Degree of success which is equal to the number of times the search time for a particular symbol was within the prescribed time limit, and met the deadlines.

All simulation results are hypothetically generated for the purpose of explanation our framework. As a future scope we intent to use more realistic data to substantiate and advance this research.

VIII. RESULTS & DICUSSIONS

We present our findings in the following graphs drawn between search times and size of the Symbol space generated, for a given value of Mutual Information or degree of correlation. We used linear search algorithm which is a simplest approach involving following steps:

- Start from the leftmost element of the given array of symbols and one by one compare the symbol that we are looking for, with each element of the array.
- If a match occurs, return the index.
- If no match occurs with any of elements, return -1.

Future implementation will be based on more advance search such as hash tables. The graph below shows the results for correlated data with correlation-coefficient r=+0.9. One of the fastest methods to generate correlated data is using the Cholesky decomposition [9].

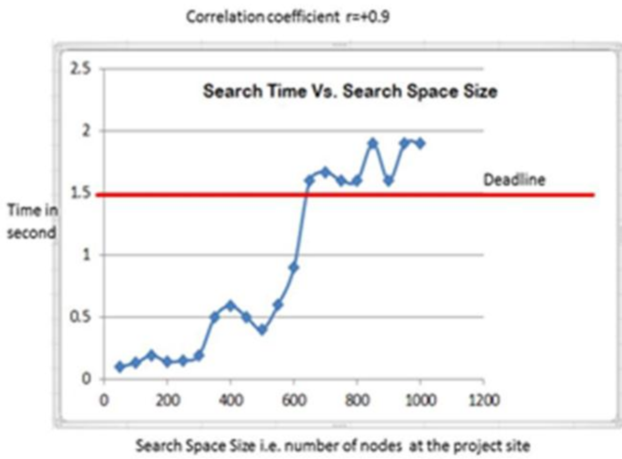

Figure 6. Simulation results

The results were obtained on Intel Core 2Duo processor with 4GB system RAM running windows 7 Operating system.

It can be seen that when the search space is less than close to 600, deadlines are met. But when the size is more than 600 deadlines are not met. What will be the consequence of not meeting deadlines will depend upon the nature of the application; for a lifesaving application is a disaster!
For applications not requiring such precise real time requirement, missing these deadlines do not pose any serious threat.

IX. CONCLUSION & FUTURE SCOPE

In this paper we have presented some results from our on-going research regarding development of a framework for improving communication reliability in situations where the connectivity is low. To explain our idea, we have taken an example where a company has deployed large number of service personals at a customer's site, though we have given other scenarios where our frame work can work. The basic assumption is that most of the information is locally available at project site and is common among all the nodes so these nodes can cooperatively exchange requested information among each other using short range communication means which almost always has good connectivity. We expressed this assumption using the concept of Mutual Information from Information theory as in (1). We have also presented a methodology to simulate and validate our concept of this framework.

A lot of work needs to be done to precisely know various pros and cons of the proposed framework. Especially more mathematically rigorous analysis is required to prove the idea. This is being proposed as a future scope of this work and is a part of our ongoing research.

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