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Systems Methodology and Framework for problem definition in Mobile ad hoc networks

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Abstract *- Mobile Ad Hoc Networks are communication networks built up of a collection of mobile devices which can communicate through wireless connections. Mobile Ad Hoc Networks have many challenges such as routing, which is the task of directing data packets from a source node to a given destination. This task is particularly hard in Mobile Ad Hoc Networks: due to the mobility of the network elements and the lack of central control, robustness and adaptability in routing algorithms and work in a decentralized and self organizing way. Through the principles of systems architecting and engineering, the problem statement in Mobile Ad Hoc Networks could be defined more specifically and accurately. The uncertainties and techniques for mitigating and even taking positive advantages of them can be achieved through a framework of uncertainties as in [1]. The systems methodology framework called Total Systems Intervention (TSI) described by Flood and Jackson [2] select a systems methodology for Mobile Ad Hoc Networks. The purpose of this paper is to show how TSI when integrated with a framework created to understand the risks and opportunities can help develop strategies to minimize the risks and to take advantage of the opportunities for facing challenges in Mobile Ad Hoc Networks.*

Keywords *– Total Systems Intervention, Uncertainties framework, problem definition, MANETs*

I. INTRODUCTION

Wireless Sensor Networks (WSN) has attracted a great deal of research importance recently due to its wide variety of applications, many critical, such as military surveillance, biological detection, remote machine diagnosis/prognosis, inventory management etc. Due to its different flavors of applications, WSN faces a number of challenges both technically and managerially. Mobile Ad-Hoc Networks (MANETs) is a flavor of WSN application which is a collection of small mobile hardware devices, referred as nodes in this paper, communicating with each other through wireless medium. MANETs face a number of challenges since the nodes are driven on very low power sources facing energy constraints, number of nodes may be higher in number, and each node is mobile. Optimum energy utilization, accurate routing of data among the nodes to the destination with minimal energy and time, ability to adapt to the dynamic environment are just a few of the challenges in MANETs.

Mobile ad-hoc networks typically are self-configuring network of nodes in which data is exchanged by exploiting the multi-hop routes that exist in the network. The nodes in MANETs move randomly without any set mobility trace which makes it an interesting problem to solve. MANETs have no fixed base stations allowing rapid deployment resulting in highly dynamic network topology changes with multi-hops and the network needs to form automatically to adapt to changes providing many design challenges [8, 9].

Complex systems are more and more developed based on the principles of Systems architecting and engineering. In communications network research, there is currently an increasing interest for the paradigm of autonomic computing such as the MANETs. The idea is that networks are becoming more and more complex and that it is desirable that they can self-organize and self-configure, adapting to new situations in terms of traffic, services, network connectivity, etc [3]. This calls in for a proper implementation of Systems engineering principles for effective design and methodology to tackle the challenges of a complex system as the MANETs.

System complexity is considered to be a continuum with the terms simple and complex bounding the ends of the scale and having the characteristics given in Table 1[3]. It can be seen that MANETs fit the "complex system" definition well. MANETs can have very large and varying number of elements (nodes) each possible interacting with each other. As the number of nodes increase the interactions also increases by manifold increasing its complexity of operation. Their attributes may not be predefined as they may change with respect to application or the changing environment. Since the nodes are mobile and can have random motions, MANETs have a probabilistic nature of behavior and continuously evolves in time with respect to its topology and communication. Any node could be added as part of the network at any point of time. The nodes may be independent in its role in the network with specific goals for itself. Wireless communications are hugely dependent on the physical environment it is being employed in.

Table 1. Definitions of System complexity [3]

Attribute	**Simple Systems**	**Complex Systems**
• Number of system elements	Small	Large
• Interactions between elements	Few	Many
• Attributes of elements	Predetermined	Not predetermined
• Interaction between elements	Highly organized	Loosely organized
• Behaviour	Governed by well-defined laws	Probabilistic
• Evolution	Does not evolve	Evolves over time
• Nature of sub-systems	Do not pursue their own goals	Are purposeful and generate their own goals
• Interaction with environment	None	Interacts strongly

The overarching challenge is in understanding the challenges, issues, problems and most importantly in defining them the right way. *"Don't assume that the original statement of the problem is necessarily the best or even the right one."*[4]. Keeping this heuristic in mind a systems methodology must be applied to arrive at the best possible problem statement from the already defined ones. The TSI-Total Systems Intervention introduced by Flood and Jackson [2] helps to identify a Systems methodology. To address the risks and uncertainties in the system the framework proposed by [1] is used in this paper aiming to minimize the risks and mitigate the opportunities.

II. SYSTEMS APPROACH

Systems behavior is dependent on the properties of the individual components and the interactions between the components. Systems thinking for complex systems is the process of employing, studying and implementing a framework which encompasses the principle of treating the system with the concept of wholeness.. It is important to appreciate that system thinking is generic and far broader than the complex systems of MANETs.

Systems thinking encompass two pairs of core concerns [6,7]. The first is emergence and hierarchy and the second pair is communication and control. In MANETs the mobile nodes would belong to a lower basic network and hierarchically be part of a higher layer and so on to form a complex network of communication. This emulates the need for control in the communication as well as effective way of communication to gain best possible control. The pair of communication and control also play an important part in defining the adaptability of the MANETs to the changing dynamics of the environment.

III. TOTAL SYSTEMS INTERVENTION – TSI

A. Introduction

Total Systems Intervention (TSI) introduced by Flood and Jackson [2] is a systems methodology process for problem definition and solving. TSI process is based on the principle of system metaphors that define or characterize the design parameters of the system as a whole. Rigorous use of the system metaphors is used to bring out a creative process to understand the issues and challenges involved. Identification of the system metaphors is critical and must be able to encompass the goals to be achieved.

A few systems methodologies may be identified and applied to understand the behavior of the system through the metaphors. The system metaphors are then analyzed through a framework linked to various systems methodologies. The advantage of TSI is in its ability to include more metaphors and system methodologies for future systems analysis.

TSI thus provides basic methodology to be based upon to systematically define the problem statement for MANETs perceiving the system as whole. The complex nature of MANETs would invariably lead to a number of uncertainties. For example, if we identify the problems in routing data packets using the TSI we would still be uncertain on how it will affect energy utilization in the nodes or the performance in terms of delay or hops. Hence, it becomes necessary to study the types of uncertainties and develop a systems methodology to tackle them. A frame work provided for understanding uncertainty and its mitigation and exploitation in complex systems by Hastings and McManus [1] form a strong foundation for our purpose in MANETs.

B. Uncertainties

A complex system would have many uncertainties which affect its design and operation. Uncertainties need not always be negative and could be studied to be mitigated. A good understanding of the uncertainties, their different types in the system and their nature would help deal with them more efficiently.

The wide range of types of uncertainties and possible responses to them make unified discussions of the problem difficult. In particular, discussion of desired advanced system characteristics such as robustness, flexibility, and adaptability is plagued by poorly defined terminology. This difficulty is particularly acute when teaching both the basic problems and the emerging techniques to students of complex system design. As an aid to discussion and teaching, a framework presented in [1] could be extended and modified for MANETs. The global problem of dealing with uncertainty is first broken into four categories, which are conceptually very different. Simplistically, uncertainties lead to Risks or Opportunities, which are handled technically by Mitigations or Exploitations, which hopefully lead to desired Outcomes [1].

Traditional engineering would only focus on the reliability and robustness in the outcomes. This framework extends to more variety of outcomes such as the versatility, flexibility, evolvability and interoperability. This framework is also different from the traditional engineering approach of concentrating only on minimizing the risks by trying look for possibilities in mitigating certain uncertainties to opportunities. Thus it is more comprehensive and highly related to systems engineering in dealing with systems as a whole.

IV. SYSTEM METAPHORS FOR MANETS

MANETs performance may be investigated through different parameters that define the QoS or the quality of service which form the basis for design of a MANET. Uncertainties are identified characterizing the metaphors and are analyzed using the framework given in [1]. System performance metrics that could be considered as system metaphors are:

A. Throughput

Throughput: amount of data that could be exchanged between a source and a destination at any given time in the MANET.

The uncertainties that affect the throughput of the MANETs include the transmission configuration, link capacity, number of nodes and links on the network and the performance of the routing protocol. The routing protocol in multiple hop networks determines the best route and would affect the amount of data traffic a node would have to handle, both as a source/destination node or a forwarding node.

Network throughput may vary depending on a lot of factors. In multi-hop networks mobility of the nodes would require the network to have dynamically adapting routing protocol for routing the data packets to its destination. The available bandwidth would also be crucial in determining the overall throughput and would in fact limit it. The available bandwidth in a channel itself is based on the uncertainties in the environment due to physical disturbances and the capacity of the channel is limited. The overall network traffic being generated will be determined by the number of source nodes in the network. Other nodes which do not act as source nodes may be forwarding nodes providing a route and ensuring delivery of data to the destination. The number of nodes thus also has a direct influence on the throughput.

The uncertainties characterizing the throughput may be classified as:

i. Number of nodes in the network – a *known unknown* – they can change dynamically as a new node may join the network adhoc at any point of time
ii. Network traffic – a *statistically characterizable variable* – based on the application the traffic being generated and sent may be analyzed and determined statistically
iii. Channel capacity - a *statistically characterizable variable* – physical modeling of the channels may be analyzed statistically to determine the available capacity on the physical channel
iv. Mobility of nodes – a *unknown unknown*- nodes in a MANET can have absolute random movements and are not restricted to a position.

These uncertainties are fit into the framework as shown in fig 1. The risks involved due to the uncertainties listed are complete failure of the nodes or the network and degradation of the performance resulting in lower throughput. For example, continuous mobility of the nodes may result in consistent change of routes reducing the overall throughput and may even cause total failure in transferring data. However, an opportunity to improve the throughput performance may be seen through an increase in the channel capacity. Exploiting/mitigating these risks and opportunities may be achieved through a proper design choice such an efficient routing protocol which can handle higher number of nodes and their mobility increasing the reliability of the network. Better channel capacity results in an upgradeability of the network through an improvement in handling higher network traffic providing robustness to various applications.

Fig. 1. Uncertainties framewrk for Throughput in MANETs

B. Delay

Delay: time taken for a data packet to reach its destination from the source to the destination; in MANETs the path from source to destination may not be direct and may involve other nodes in the route from source to destination involving "multiple hops".

Time taken for wireless communication between two nodes is directly dependent on the distance between the nodes. However, in MANETs multiple hops may be required when the nodes do not have direct access to each other which may be due to obstacles in the physical environment or may be the nodes are too far away for direct communication. This, the routing protocol largely affects the end to end delays in a MANET. The routing protocol must also be effective in self-organizing and adaptive to the changes in the topology of the network as the mobiles are mobile. Also, the range between two nodes also depends on the transmission capability of the node and the minimum energy required for a node to receive a wireless signal.

The delay may be affected by the uncertainties involved with the number of hops in the route from source to destination which are determined by the routing protocol being used. Mobility of the nodes would dynamically change the number of hops required for a source destination pair. Also, the time for wireless communications is dependent on the distance between the communicating nodes which in turn varies according to the mobility of the nodes. The data packets can also get significantly delayed at a particular node if the node has a high amount of data to be processed resulting in queuing delays. Insufficient buffer size in a node may even result in data being dropped. The amount of data to be processed may in turn be dependent on the network traffic. Channel capacity between two links limits the data being sent between two nodes and would also affect the amount of data being processed by a node.

The uncertainties characterizing the delay may be classified as:

i. Moblility – a *unknown unknown*
ii. Network traffic – a *statistically characterized variable*
iii. Channel capacity - a *statistically characterized variable*
iv. Number of hops in a route – a *known unknown* – they are determined by the routing protocol
v. Environment – *lack of knowledge* – the obstacles in the path between two nodes can vary from place to place and cannot be determined
vi. Node buffer size – a *statistically characterized variable* – they are determined using queuing theory and analysis based on the anticipated network traffic and topology.

These uncertainties are fit into the framework as shown in fig 2. The uncertainties discussed can all seriously affect the end to end delay for data in a MANET. The number of hops and the node buffer size may be considered as metrics that directly quantify the delay. Also, the node buffer size may be improved for lesser delays; on the other hand it also provides an opportunity of improving the through put as an emerging capability. Design choices such as optimal buffer sizes and routing protocol with consideration to minimizing redundancy in data over the network may be employed for better reliability and evolvability of the system.

Fig. 2. Uncertainties framework for Delay in MANETs

C. Node-lifetime

Node-lifetime: since the nodes in MANETs run on constrained energy sources such as the batteries, the lifetime of the node become critical that would define the amount of time the node could be even a part of the network "alive and not dead". The lifetime of a node in wireless networks depends entirely on the energy available at the node and the rate at which it is being used. It is critical to understand the behavior of the node in terms of it being 'active' to determine its lifetime.

In multi-hop wireless networks a node may act as a source, destination or forwarding node. Routing protocols are largely responsible for a node in the network to behave as a forwarding node and thereby increasing the time required for a node to be active in the network. Energy efficient routing protocols thus need to be efficient in selecting nodes for route selections that directly determine the lifetime of the nodes. Also, a node may not be required to send data at its maximum possible power to communicate with other nodes. The transmission configuration of the nodes which determines the power of transmission from a node would significantly affect the node lifetime. Power-adaptive protocols and strategies may be used to optimize the power required for wireless transmissions, thereby increasing the node-lifetime [10].

The uncertainties characterizing the node lifetime may be classified as:

i. Transmission configuration – a statistically characterized variable – the transmission power is either constant or determined by the power adaptive control algorithm in place
ii. Initial available energy – a statistically characterized variable – this is always known and may be determined at any instant
iii. Network traffic – a statistically characterized variable.

These uncertainties are fit into the framework as shown in fig 3. These uncertainties involve risks of degradation, complete failure of node or disaster by completely running out of energy. However, power adaptive control algorithms provide means of adding extra capacity in terms of energy available to the node. Good design choices with energy efficiency considerations and avoiding redundancy of data to minimize the number of transmissions must be taken care of to improve the node lifetime. Verification and testing of these must be done to ensure a minimum node life for a MANET.

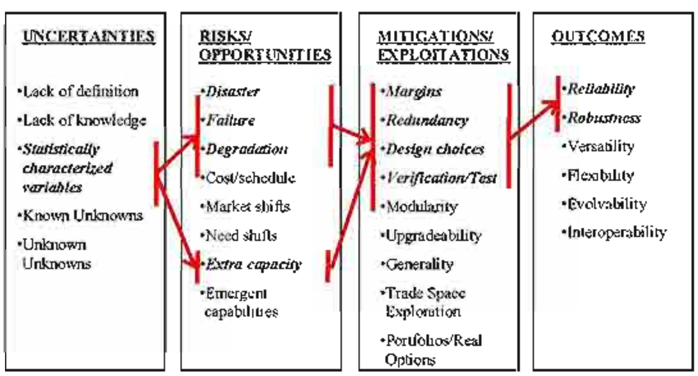

Fig. 3. Uncertainties framework for Node-lifetime in MANETs

V. RESULTS AND DISCUSSION

By characterizing the metaphors from the TSI approach using the uncertainties framework helps us visualize the inherent uncertainties, risks, opportunities and exploit them to design a robust, flexible MANET. To illustrate the approach, a simple network topology is simulated where the metaphors are incrementally included in the decision making process. It consists of the following:

- Static nodes - a number of co-located, network enabled wireless nodes that transmit/receive information over the network.
- Mobile nodes - these are nodes which randomly move across the network grid and act as source, destinations and forwarders of network traffic. This helps us model a realistic network with interference effects due to mobility.

Communication in the network is randomly established between static and mobile nodes. The nodes randomly transmit data in addition to the network management packets (for route establishment). Random packet generation time was assumed to ensure a realistic traffic pattern.

A. Simulation parameters

The performance of the proposed scheme was evaluated using the Ns2 simulator. The following values were used for both the sets of simulations unless explicitly specified: the mobility model and the end-to-end connections to be established were randomly generated using the packages available in Ns2. The simulation topology includes a total of 21 nodes: 15-mobile and 6-static over a 700m*700m network grid. The sources were modeled to generate uniform packets, the queue limit at each node was taken as 50, and the packet size was taken as 512 bytes. The simulation was repeated thrice. The routing protocol was changed between the two simulation experiments to see the impact of just considering Throughput.

B. Simulation methodology

To begin with, the 'throughput' metaphor is selected for analysis and the design parameters were chosen so as to maximize the throughput in the network. Later, we incrementally introduce the 'delay' metaphor and make the necessary design changes so as to reduce the delay between the different sources and destination. The sending and dropping throughput (bits/sec), the end-to-end delay in transmission between static and mobile nodes are selected for evaluating the performance changes induced by the changes in the design.

C. Results and Analysis

Case 1: Throughput - We have selected AODV as the routing protocol for this case, because AODV sets up the network as soon as the nodes start communicating. Also it is expected to have lesser network overhead once the network is established. Fig 4 and 5 show the sending and dropping throughput for this case. The fluctuation of network throughput and the dropping of data can be attributed to the randomness injected into the network sources, the mobility of the nodes in the network and interference effects. However, it cannot be inferred if we have achieved the best performance by just considering one metaphor. The TSI stipulates to consider all possible metaphors to come up with a perfect design. Hence, we introduce next metaphor for analysis to see if it helps define the problem in MANETs better.

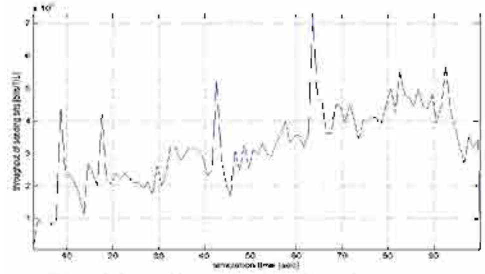

Fig. 4. Throughput of sending bits for case 1

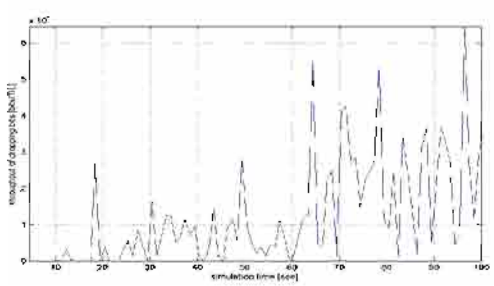

Fig. 5. Throughput of dropping bits for case 1

Case 2: Delay - In this case, we chose DSDV, because its a reactive routing protocol and can be faster in setting up alternate routes when the nodes are highly mobile thereby reducing the overall delay in the transmission. Fig 6 and 7 show the delay using the newly chosen set of design parameters between two static and two dynamic pair of nodes respectively. As expected, the delays of the mobile nodes are a little higher than that of the static nodes.

To visualize the change in performance lets compare figs 6 and 7 with figs 8 and 9 respectively. Figs 8 and 9 are the delay graphs the between two static and two dynamic pair of nodes respectively in case 1. We can observe that the delay graphs in case 1 are relatively higher compared to case 2. This trend is visible both in the static and mobile node scenarios. The severe fluctuation in end-end delay graphs case 1 can be attributed to the node mobility and the inconsistencies arising in data transmission because of that.

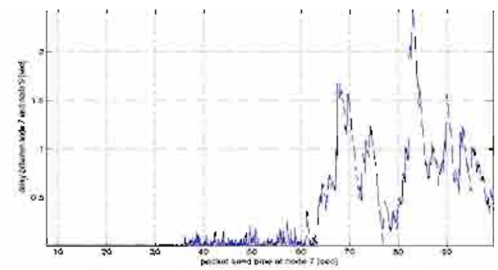

Figure 6: End to end delay between static nodes for case 1

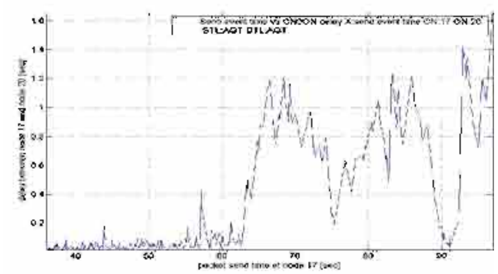

Fig. 7. End to end delay between mobile nodes for case 2

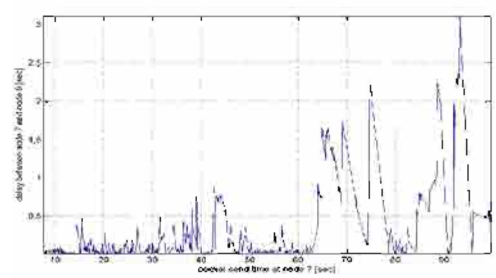

Fig. 8. End to end delay between static nodes for case 1

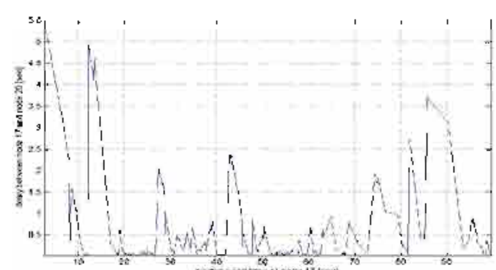

Fig. 9. End to end delay between static nodes for case 1

Though, we have achieved better performance in case 2 with the changes, it is important to look at the throughput performance. Figs 10 and 11 show the sending and dropping throughput for the case 2. Surprisingly, we can see that the sending throughput has significantly improved. In addition, the dropping throughput has gone down. The mobility of the nodes hampers the amount of data transferred and its inherently solved by the choice of a reactive routing protocol. We should note that the advantage in choosing a reactive routing protocol has helped us surface an inherent opportunity which automatically helps us improve the throughput.

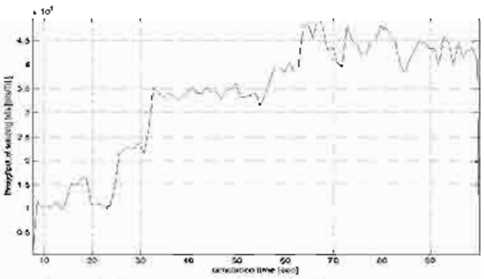

Fig. 10. Throughput of sending bits for case 2

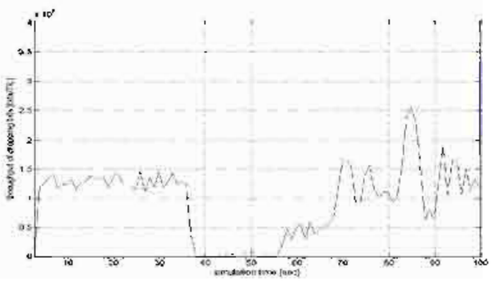

Fig. 11. Throughput of dropping bits for case 2

Though it is interesting to see the case 2 design parameters perform better in both scenarios, the reasons for that are 1) lack of a thorough problem definition, and 2) selection of a probable solution by not considering all the metaphors. The proposed approach involving TSI and the uncertainties framework helps us identifying these issues early and avoiding the risks.

VI. CONCLUSIONS

In this paper, we have presented a model where we utilized the total system intervention concepts to identify system specific methodologies to solve the design problem in MANETs. In addition, the metaphors identified from the total system intervention concept are integrated with the framework of uncertainties to solve the design problems effectively. To illustrate the proposed approach, we have selected a very simple problem and applied the concept for solving the problem of improving performance in Mobile Ad hoc Networks. MANETs are investigated by choosing these simple system metaphors - throughput, delay and node-lifetime. These metrics that affect these parameters are later analyzed using the uncertainties framework which will help us identify the risks, mitigate them and more importantly exploiting the opportunities.

To measure the performance of the proposed systems approach we perform fairly simple simulations and have presented the results. The result shows that the proposed systems methodology assures us of the effectiveness in problem definition when TSI is integrated with a framework of uncertainties. The approach could be applied to more complex systems with greater number of metaphors and larger uncertainties for characterizing and analyzing the challenges in the system.

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