Abstract
Characterized by their flexibility to be deployed and functional in “on-demand” situations, combined with their capability to transport a wide spectrum of applications and resilience to dynamically ‘heal’ around failed network elements, mobile ad hoc networks (MANETs) are gaining rapid momentum both in the commercial and military arenas. Illustrative examples in the commercial sector include the need for establishing communications in disaster areas and/or rural places where it becomes difficult to deploy fixed infrastructures. In the military sector, MANETs are becoming the basis for the future network-centric warfare (NCW) paradigm as exemplified by the Future Combat Systems (FCS) and Warfighter Information Network-Tactical (WIN-T) programs. The success of MANETs is however critically tied to their capability of transporting a wide spectrum of applications with varying quality of service (QoS) requirements, and providing continued/un-interrupted service (i.e., seamless recovery) despite failures in the underlying network.

Failures in MANETs can be classified as belonging to two broad families or classes: (a) the class of “hard” failures and (b) class of “soft” failures. A hard failure is defined as a failure that is associated with equipment typically an equipment failure or malfunction. The root cause analyses of hard failures are typically deterministic in nature, i.e., the fact that a piece of equipment is broken or not is diagnosed with probability 1. A soft failure is defined as a failure that is associated with performance degradation. Examples of soft failures include service degradation due to excessive loss and/or delay. Soft failures are typically stochastic in nature – i.e., the “root cause” of any particular soft failure is difficult to diagnose with absolute certainty, and therefore the probability that a given root cause diagnosis for a soft failure is correct lies somewhere between 0 and 1. For example, the root cause explaining why packets are being dropped in large numbers could be (a) excess application traffic, (b) a denial of service attack that floods with network with traffic, (c) equipment malfunction that causes excessive retransmissions, and so on.

MANETs by their very nature are stochastic – in part because of the unpredictable environmental conditions and mobility of the MANET nodes, and in part because of the scarcity and variability of bandwidth resources. Thus a majority of failures in MANETs are soft failures. This is in contrast to wireline networks, which are rarely subject to soft failures, due to significant over-provisioning of network capacity. Also, wireline networks typically function under benign environmental conditions, as they are typically not subjected to adverse environmental effects such as temporal fading that produce fluctuating bandwidth, or mobility changes that result in variable network topology. Soft failures are therefore less frequent in wireline networks, as compared to the dynamic and unpredictable wireless mobile ad hoc networking environments.

This tutorial addresses the complex topics of fault and performance management for MANETs. Via the use of novel fault and performance management techniques that can adapt
to the dynamics of the underlying MANET, the tutorial will describe techniques to provide resilience and service assurances to a wide spectrum of applications with diverse QoS requirements. The principal functions of fault management, namely network monitoring and root cause analysis, will be discussed. Root cause analysis, in particular, is a function that becomes much more complex in MANETs – as compared to wireline networks – due to the dynamic and stochastic nature of these networks. We will examine the complexities of analyzing faults in a MANET environment. Another very important aspect of fault management, self-healing, will also be discussed. Given that MANETs are more prone to failures than wireline networks, it is imperative that MANETs provide the ability to automatically recover from different types of faults, whenever possible. We will look at descriptions of various fault scenarios, and the corresponding self-healing actions that can be performed to recover from these faults using a policy-driven framework.

The discussion of performance management will describe the functions required to manage the performance of applications in a MANET. Aside from the collection and aggregation of performance statistics, which is a requirement for any type of network, a performance management system for MANETs must also be able to provide quality of service (QoS) guarantees for the applications running in the MANET. Unlike wireline networks that are typically characterized by an abundance of capacity, MANETs generally provide very limited bandwidth that needs to be carefully managed so that higher priority traffic receives better treatment than lower priority traffic when there is resource contention. To further exacerbate the problem, many military MANETs have a mix of un-encrypted (red) and encrypted (black) network segments along an application’s end-to-end path, resulting in very limited (if not no) visibility into the encrypted network segments. The QoS guarantees however have to be provided along an end-to-end path, despite the presence of any intermediate black network segments. Therefore, an important aspect of performance management in MANETs is the provision of service assurances to high-priority applications, sometimes at the expense of lower-priority applications, keeping in mind any security-related (i.e., red-black) restrictions. This section of the tutorial will provide background on this problem, including the challenges in providing end-to-end service quality in MANETs characterized by heterogeneous networking technologies and encrypted and unencrypted network segments. An approach to providing quality of service using adaptive measurement-based admission control and dynamic quality adjustment will be discussed in detail, including the required functions and related algorithms that support management of QoS in MANETs.

This tutorial will be partly based on a book recently co-authored by Dr. Latha Kant entitled “Policy-Driven Mobile Ad Hoc Network Management” [1].

NOTE: A related tutorial proposal, “Policy-Based Network Configuration Management for MANETs” by Dr. Ritu Chadha, will provide an in-depth treatment of the use of policy-based management for configuration of MANETs. Dr. Chadha is the co-author of the book [1].

**Target Audience**
Target audience for this tutorial includes researchers, professionals and advanced graduate students in the field of IP and MANET management. The tutorial is also targeted for researchers and professionals that are engaged in network management for wireless infrastructure networks, since this tutorial will cover several challenges that are unique to management of wireless networks and contrast them with their wireline counterparts. With MANETs becoming the *basis* of the future network centric warfare (NCW) program, the
need for “intelligent” network management techniques that provide seamless service restoration amidst network element failures and QoS guarantees to the wide spectrum of applications that will use these MANETs, becomes critical. More specifically, since the NCW (as well as MANETs deployed in commercial disaster areas), will be expected to carry and deliver mission critical information that require stringent delay and loss requirements, together with regular (also referred to as ‘routine’) applications that albeit not very sensitive to delay require intact delivery, the presence of fault and performance management systems that can adapt to the network conditions is crucial. To this end, the focus of this tutorial will be on adaptive/dynamic fault and performance management operations in IP-based MANETs. Additionally, by introducing a variety of open research issues in the field of MANET fault and performance management to the audience, this tutorial will be beneficial to professionals and researchers (both in the industry and academia) in the area of MANET management and design.

Content
This tutorial will cover the following topics:
• Salient differences between wireline and MANET fault and performance management;
• Overview of the challenges of managing faults and performance in mobile ad hoc networks
• Methodologies for providing service survivability in the face of both hard (deterministic) and soft (stochastic) failures in MANETs using a policy driven framework, along with case studies;
• Differentiated Services (DiffServ)-based Quality of service (QoS) management for MANETs characterized by heterogeneous networking technologies and a mix of un-encrypted and encrypted transport network segments; and
• Important open research issues in the area of MANET fault and performance management.

Presenter Biography
Latha Kant (Ph.D., Electrical and Computer Engineering) is Senior Scientist and Director of the Mobility Management research group in Applied Research at Telcordia Technologies, where she has been working since 1996. Her research interests and expertise span wireless ad hoc networking and network management, as well as performance modeling and analyses of MANETs. She has led and managed several research projects at Telcordia. Currently, she is the technical lead of the QoS team within Telcordia’s Future Combat Systems (FCS) program, where she is leading a team of researchers to develop end-to-end QoS solutions for heterogeneous multi level security networks. She has also led several projects on MANET performance modeling and analysis including Telcordia’s internal research and development efforts on scalable mechanisms for MANET performance analysis and the CERDEC DRAMA sub-task on scalable modeling and analysis of a dynamic policy-based network management system for MANETs. Dr. Kant is also currently leading a research effort on Network Science as part of the Army Research Laboratory (ARL) Communications & Networks (C&N) task on Survivable Wireless Mobile Networks (SWMN) with a focus on fundamental research in the area of MANETs. Prior to joining Telcordia Technologies, Dr. Kant worked with the communications systems division of the India Space Research Organization (ISRO), subsequent to completing her Bachelors of Engineering in Electrical and Electronics Engineering. As a research scientist with ISRO, she was part of the team that designed on-board and ground communications systems for satellite networks. Dr. Kant has published over 40 papers in journals and conferences, and holds a patent on selfhealing
mechanisms in packet-switched networks. Dr. Kant is a member of Etta Kappa Nu, Engineering Honors Society.

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