Capacity Constrained MANETS: Adaptive Policy-Driven Fault and Performance Management

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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 or **service level agreements** (**SLAs**), and providing continued/un-interrupted service (i.e., seamless recovery) despite failures in the underlying network.

Failures 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 **policy-driven 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 MANETs have a mix of un-encrypted (red) and encrypted (black) network segments to capture **varying security requirements** 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 un-encrypted 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].

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.

Biography of speaker

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 self-healing mechanisms in packet-switched networks. Dr. Kant is a member of Etta Kappa Nu, Engineering Honors Society.

Recent Related Publications

1. R. Chadha and ***L. Kant***, "*Policy-driven Mobile Ad Hoc Network Management*", John Wiley & Sons, ISBN: 978-0-470-05537-3, November 2007.
2. K. Chang, P. Gopalakrishnan, ***L. Kant***, K.R. Krishnan, A. McAuley, K Manousakis & K Young, *"NEDAT – A Network Engineering Design Analytic Toolset to design and analyze large scale MANETs"*, IEEE MILCOM, Florida, October 2007.
3. P. Gopalakrishnan, ***L. Kant*** & K.R. Krishnan, *"Wireless Network Design with Directional Antennas"*, IEEE MILCOM, Florida, October, 2007.
4. S. Demers, P. Gopalakrishnan and ***L. Kant***, *"A Generic Solution to Software-in-the-loop"*, IEEE MILCOM, Florida, October, 2007.
5. ***L. Kant***, F. Anjum & K. Young, *"Design and analysis of Scalable Network Centric Warfare Mechanisms"*, Proceedings of the 25th Army Science Conference (ASC), Florida, November 2006.
    a. ***<u>Recipient of Best Paper Award</u>***
6. A. Poylisher, F. Anjum, ***L. Kant,*** R. Chadha, "*QoS Mechanisms for Opaque MANETs*", IEEE MILCOM, Washington DC, October 2006.
7. S. Demers & ***L. Kant***, *"MANETs – Performance Analysis and Management"*, IEEE MILCOM, Washington DC, October 2006.
8. J.Chiang, S. Demers, P. Gopalakrishnan, ***L. Kant***, A. Poylisher, Y-H. Cheng, R. Chadha, G. Levin, S. Li & Y. Ling; *"Performance Analysis of DRAMA – A distributed policy-based system for MANET Management"*, IEEE MILCOM, Washington DC, October 2006.
9. ***L. Kant*** and C-W. Lee, "*Discrete Event Simulations, Mobile Ad hoc networks and Scalability"*, IASTED Applied Simulation and Modeling (ASM) conference, Greece, June 2006.
10. P. Gopalakrishnan, S. Demers & ***L. Kant***, *"Speedup Techniques for Analyzing Large Scale Mobile Ad hoc Network Management Systems"*, IEEE Mobile Wireless Network Symposium, Canada, June 2006.
11. ***L.Kant***, S.Demers, P.Gopalakrishnan, R.Chadha, L.LaVergne & S.Newman, *"Performance Modeling and Analysis of a Mobile Ad Hoc Network Management System"*, IEEE MILCOM, Atlantic City, October 2005.
12. S.Erramilli, J.Lee, ***L.Kant***, A.McAuley, J.Giacopeli, K.Adams & J.Pulliam, *"Modeling and Analysis of Routing for Heterogeneous Multi-tier Ad Hoc Networks"*, IEEE MILCOM, Atlantic City, October 2005.
13. ***L. Kant***, C-W Lee, Y.Ling, W.Chen, *"Fault Tolerance via Adaptive Cross-layer Self-healing Mechanisms in Adhoc Networks"*, Proceedings of ICANS, Singapore, June 2005.

14. C. Sadler, ***L. Kant*** and W.Chen, "*Cross layer Self-healing Mechanisms in Wireless Networks*", Proceedings of the World Wireless Congress' B3G (Beyond 3G), San Francisco, May, 2005.
15. ***L. Kant*** and W.Chen, "*Service Survivability in Wireless Networks via Multi-Layer Self-Healing*", IEEE WCNC, New Orleans, March, 2005.
16. ***L. Kant***, W.Chen, C-W. Lee, A. Sethi, M. Lei, C.Shen, *"D-FLASH : Dynamic Fault Localization And Self-Healing for battlefield networks"***,** Proceedings of the 24th Army Science Conference (ASC), Orlando, December 2004.
17. ***L. Kant***, and W. Chen, *"Alarm Model Specification and Dynamic Multi-layer Self-healing mechanisms for commercial and ad-hoc wireless networks"*, IEEE PIMRC, Spain, September 2004.
18. F.Anjum, S.Das, P. Gopalakrishnan, ***L.Kant*** and B.Kim, „Integrated Wireless Security", WWRF (World Wireless Research Forum), Oslo, June 2004.
19. I. Joe and ***L. Kant***, *"SCTP Through Improved Cookie Mechanism for Wireless Networks via Modeling and Simulation"*, IEEE Vehicular Technology Conference (VTC 03), Florida, October 2003.
20. ***L. Kant***, A. McAuley, R. Morera, A.S. Sethi, M. Steinder, *"Fault Localization and Self-Healing with Dynamic Domain Configuration"*, IEEE MILCOM, Boston, October 2003.
21. ***L. Kant***, "*Integrated Fault Performance and Configuration Management System in Next Generation Wireless Communications (3G+) Networks"*, Proceedings of "3G Wireless 2003", World Wireless Congress, San Francisco, May 2003.
22. ***L.Kant***, A.Sethi, M.Steinder, "Fault Localization and Self-healing Mechanisms for FCS Networks", Army Science Conference (ASC-02), Florida, December 2002.
    a. ***Recipient of Best Paper Award***
23. ***L. Kant***, *"Fault Management and Design of Wireless Root Cause Analysis Engines for 3G Networks", Proceedings of "3G Wireless 2002"*, World Wireless Congress, San Francisco, May 2002.
24. ***L. Kant***, *"Design and Performance Modeling & Simulation of Self-healing Mechanisms for Wireless Communications Networks"*, Proceedings of the 35th Annual Simulation Symposium, San Diego, April 2002.