PERFORMANCE AND DEPENDABILITY ANALYSIS OF MOBILE COMMUNICATION NETWORKS : A STOCHASTIC MODELING APPROACH

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by

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Department of Mathematics

submitted
in fulfillment of the requirements of the degree of Doctor of Philosophy

to the

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To my Parents

Certificate

This is to certify that the thesis entitled **"Performance and Dependability Analysis of Mobile Communication Networks: A Stochastic Modeling Approach"** submitted by **Ms. Anupam** to the Indian Institute of Technology Delhi, for the award of the Degree of **Doctor of Philosophy**, is a record of the original bonafide research work carried out by her under my supervision. The thesis has reached the standards fulfilling the requirements of the regulations relating to the degree. The results obtained in this thesis have not been submitted in part or full to any other university or institute for the award of any degree or diploma.

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Abstract

The efficiency of mobile communication networks depends critically on its performance and dependability attributes. One of the large-scale performance issues is to maintain the battery life of the mobile devices (user equipments). Mobile devices have come to be equipped with a variety of peripherals which includes, acceleration sensors, cameras, GPS, online gaming, etc. On one side they offer convenience to the user, on another side they lead to high power consumption. The problem of short battery life has fundamental importance among researchers, academicians and mobile device developers. Mobile devices especially smartphones are powered by batteries which are limited in size as well as capacity. Hence, maintaining the power consumption issue in them is a need of the hour in next-generation wireless network technologies.

Hardware or software component failures include manipulating system through software changes, natural or man-made disasters, etc. Therefore, an obvious question arises which ask, how to build and evolve network architecture to cope with any major physical or software attack so that critical information systems can still communicate by utilizing the remaining available resources. Hence, future generation wireless technologies are required to deal with the dependability issues of the network. Dependability attributes such as availability, reliability, safety, integrity, and maintainability are required to be taken into consideration substantially by future generation communication networks developers. These attributes serve as the performance measures to quantify the quality of service.

In this thesis, we deal with the power saving issue by employing Discontinuous Reception (DRX) mechanism in Long Term Evolution- Advanced (LTE-A) networks and conducting performance analysis for the system considered. A selection criterion is proposed for choosing DRX mechanism parameters in case of one-way and two-way communication of voice traffic. Therefore, by exploiting the properties of the voice traffic, DRX parameters are selected. In the same spirit, a model is proposed, which begins the DRX mechanism in an user equipment depending upon the type of traffic running at the end user. Further, this model is mapped with a vacation queue model with N policy and analyzed mathematically. The optimal number of DRX cycles and N are obtained for the maximum power saving.

Other than this, to analyze the behavior of battery charge content of a DRX enabled user equipment, a fluid queue model is proposed and investigated. In future, it will help the researchers and developers in manufacturing high-performance batteries for the next generation wireless devices. To perform the performance analysis for these models, techniques such as continuous time Markov chains (CTMCs), fluid queue and vacation queue modeling are used.

A hierarchical model is proposed for reliability and survivability analysis of LTE-A networks. It is further classified into upper level and lower level models. Upper level models are reliability block diagrams (RBDs) whereas lower level models are CTMCs. This classification is performed to capture a realistic approach towards modeling, because dependent behavior and repair of failed components, etc., are not taken into account by an RBD model. Dependability attributes such as reliability, availability, etc., are investigated.

Finally, for achieving efficient radio resource management in next generation communication networks, existing and new technologies are combined to provide high bandwidth access anytime and anywhere for different types of services such as real-time data services, non-real time data services, etc. To manage the radio resources, a call admission control scheme is proposed for heterogeneous network environment. Performance analysis is presented by considering UMTS, LTE and LTE-A communication networks under this joint scheme. Modeling technique, called generalized stochastic Petri nets is used for the performance analysis.

सार

मोबाइल संचार नेटवर्क की दक्षता इसके पर्फोमसं और निर्भरता गुण पर गंभीर रूप से निर्भर करती है। बड़े पैमाने पर पर्फोमसं के मुद्दों में से एक है मोबाइल उपकरणों का जीवन (उपयोगकर्ता उपकरण)। मोबाइल उपकरणों को विभिन्न परिधीय उपकरणों से लैस किया गया है जिनमें त्वरण सेंसर, कैमरा, जीपीएस, ऑनलाइन गेमिंग इत्यादि शामिल हैं। एक तरफ वे उपयोगकर्ता को सुविधा प्रदान करते हैं, दूसरी ओर वे उच्च शक्ति खपत को बढ़ाते है। शोधकर्ताओं, शिक्षाविदों और मोबाइल डिवाइस डेवलपर्स के बीच लघु बैटरी जीवन की समस्या का मौलिक महत्व है। विशेष रूप से मोबाइल डिवाइस स्मार्टफोन बैटरी द्वारा संचालित होते हैं जो आकार और क्षमता में सीमित होते हैं। इसलिए, वायरलेस नेटवर्क प्रौद्योगिकि में बिजली खपत की समस्या का समाधान खोजना अगली पीढ़ी की आवश्यकता है।

हार्डवेयर या सॉफ़्टवेयर घटक विफलताओं में सॉफ़्टवेयर परिवर्तन, प्राकृतिक या मानव निर्मित आपदाओं आदि के माध्यम से सिस्टम में हेरफेर शामिल है। इसलिए, एक स्पष्ट सवाल उठता है जो किसी भी प्रमुख भौतिक या सॉफ्टवेयर हमले से निपटने के लिए नेटवर्क आर्किटेक्चर का निर्माण और विकास कैसे करे,ताकि महत्वपूर्ण सूचना प्रणाली शेष उपलब्ध संसाधनों का उपयोग करके अभी भी संवाद कर सकें। इसलिए, भविष्य की पीढ़ी वायरलेस प्रौद्योगिकियों को नेटवर्क की निर्भरता के मुद्दों से निपटने की आवश्यकता है। भविष्य में पीढ़ी के संचार नेटवर्क डेवलपर्स द्वारा उपलब्धता, विश्वसनीयता, सुरक्षा, अखंडता और रखरखाव जैसी निर्भरता विशेषताओं को काफी हद तक ध्यान में रखना आवश्यक है। ये गुण सेवा की गुणवत्ता को मापने के लिए प्रदर्शन उपायों के रूप में कार्य करते है।

इस थीसिस में, हम लॉन्ग टर्म इवोल्यूशन-एडवांस्ड (एलटीई-ए) नेटवर्क में टूटनेवाला रिसेप्शन (डीआरएक्स) तंत्र को नियोजित करके सिस्टम के लिए पर्फोमसं विश्लेषण आयोजित करके बिजली बचत मुद्दे से निपटते हैं। वॉयस ट्रैफिक के एक तरफा और दो-तरफा संचार के मामले में डीआरएक्स तंत्र पैरामीटर चुनने के लिए एक चयन मानदंड प्रस्तावित किया है। इसलिए, आवाज यातायात के गुणों का शोषण करके, डीआरएक्स पैरामीटर का चयन किया जाता है। एक मॉडल प्रस्तावित किया जाता है, जो अंतिम उपयोगकर्ता पर चल रहे आवाज यातायात के प्रकार के आधार पर उपयोगकर्ता उपकरण में डीआरएक्स तंत्र शुरू करता है। इसके अलावा, इस मॉडल को N पॉलिसी के साथ एक छुट्टी कतार मॉडल के साथ मैप किया गया है और गणितीय विश्लेषण किया गया है। अधिकतम बिजली की बचत के लिए डीआरएक्स चक्र और N की इष्टतम संख्या प्राप्त की है। इसके अलावा, एक डीआरएक्स सक्षम उपयोगकर्ता उपकरण की बैटरी चार्ज सामग्री के व्यवहार का विश्लेषण करने के लिए, तरल कतार मॉडल का प्रस्ताव और जांच की है। भविष्य में, यह अगली पीढ़ी के वायरलेस उपकरणों के लिए उच्च पर्फोमसं बैटरी बनाने में शोधकर्ताओं और डेवलपर्स को मदद करेगा । इन मॉडलों के लिए पर्फोमसं विश्लेषण करने के लिए, निरंतर समय मार्कोव चेन (सीटीएमसी), तरल कतार और छुट्टी कतार मॉडलिंग जैसी तकनीकों का उपयोग किया जाता है।

एलटीई-ए नेटवर्क की विश्वसनीयता और जीवितता विश्लेषण के लिए एक पदानुक्रमित मॉडल का प्रस्ताव दिया है। आगे इसे ऊपरी स्तर और निचले स्तर के मॉडल में वर्गीकृत किया है। ऊपरी स्तर के मॉडल विश्वसनीयता ब्लॉक आरेख (आरबीडी) हैं जबकि निचले स्तर के मॉडल सीटीएमसी हैं। यह वर्गीकरण मॉडलिंग के प्रति यथार्थवादी दृष्टिकोण को पकड़ने के लिए किया जाता है, क्योंकि असंतुलित व्यवहार और असफल घटकों की मरम्मत इत्यादि को आरबीडी मॉडल द्वारा नहीं लिया जाता है। विश्वसनीयता, उपलब्धता इत्यादि जैसे निर्भरता गुणों की जांच की जाती है।

अंत में, अगली पीढ़ी के संचार नेटवर्क में कुशल रेडियो संसाधन प्रबंधन को प्राप्त करने के लिए, मौजूदा और नई प्रौद्योगिकियों को उच्च बैंडविड्थ पहुंच प्रदान करने के लिए संयुक्त रूप से विभिन्न प्रकार की सेवाओं जैसे रीयल-टाइम डेटा सेवाओं, गैर-वास्तविक समय डेटा सेवाओं इत्यादि के लिए संयुक्त किया जाता है। रेडियो संसाधनों का

प्रबंधन करने के लिए, विषम नेटवर्क वातावरण के लिए एक कॉल प्रवेश नियंत्रण योजना का प्रस्ताव है। इस संयुक्त योजना के तहत यूएमटीएस, एलटीई और एलटीई-ए संचार नेटवर्क पर विचार करके पर्फोमसं विश्लेषण प्रस्तुत किया है। मॉडलिंग तकनीक, जिसे सामान्यीकृत स्टोकास्टिक पेट्री नेट कहा जाता है, पर्फोमसं विश्लेषण के लिए उपयोग किया है।

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3GPP	Third Generation Partnership Project
4G	Fourth Generation
BE	Best effort
BS	Base Station
CA	Carrier Aggregation
CAC	Call Admission Control
CTMC	Continuous Time Markov Chain
CDF	Cumulative Distribution Function
DRX	Discontinuous Reception
GSPN	Generalized Stochastic Petri Nets
i.i.d.	Independent and Identical Distribution
JCAC	Joint Call Admission Control
LST	Laplace Stieltjes Transform
LTE	Long Term Evolution
LTE-A	Long Term Evolution Advanced
MAC	Medium Access Control
MIMO	Multiple Input Multiple Output
MTTF	Mean Time To Failure
NRT	Non Real Time
ODE	Ordinary Differential Equation
PDDCH	Physical Downlink Control Channel
PDE	Partial Differential Equation
PDF	Probability Density Function
RAT	Radio Access Technology
RRC	Radio Resource Control
RRM	Radio Resource Management
RT	Real Time
SHARPE	Symbolic Hierarchical Automated Relaibility and Performance Evaluator
SPN	Stochastic Petri Nets
TDD	Time Division Duplexing
QoS	Quality of Service
UE	User Equipment
UMTS	Universal Mobile Telecommunication Systems

WiMAX	World Wide Interoperability for Microwave Access