Projects Description

A. <u>Traffic Grooming in Optical Networks</u>

Due to their tremendous transmission bandwidth, wavelength division multiplexing (WDM) optical networks are primarily used as the transport infrastructure of higher-layer client networks to deliver client traffic from one point to another point. The research on WDM optical networks has traditionally assumed that traffic demands are at the wavelength granularity, and a lightpath is established on a fiber route to satisfy a traffic demand, by reserving one wavelength on each hop. However, traffic demands from clients are typically at the sub-wavelength granularity and have heterogeneous bandwidth requirements. As such, there have been many studies on traffic grooming recently, which considers how to route and consolidate sub-wavelength client connections onto lightpaths. Traffic grooming in WDM optical networks can be classified into static or dynamic, depending on whether the sub-wavelength client connections are given in advance, or randomly arrive/depart.

i) Theoretical Performance Analysis of Traffic Grooming (2002 - present)

The focus of our study is to conduct performance analysis of dynamic traffic grooming in WDM optical networks with a mesh topology. Although there have been many studies on performance analysis of the mesh optical network, to our best knowledge, the performance analysis of traffic grooming has not yet been studied and our work is the first in the literature. The blocking analysis of client traffic in traffic grooming is much different from and more difficult than the lightpath blocking analysis in a single optical network, because in traffic grooming, the client traffic blocking is conditioned on the lightpath blocking in the optical network, which is quite difficult to obtain as it is very difficult to derive the lightpath arrival process from the given client traffic process, and even more difficult to apply analysis on the resulted lightpath arrival process. We have addressed this challenge through transforming the physical client traffic offered to the lightpaths into the fictitious client traffic that is fictitiously offered to the link in the optical network. This approach, however, raises a new challenge, i.e., the client traffic from different source client nodes cannot be simultaneously carried on the same wavelength in a link. By using the continuous time Markov process, queueing theory, and theory of multi-service loss system, we have addressed this issue through developing several traffic-source differentiating link blocking models, under the assumption of Poisson arrival, exponential holding time, and arbitrary bandwidth distribution for the client traffic. We have extended the technique of reduced load approximation to develop several analytical models to compute the end-to-end client traffic blocking probability for each source-destination client nodes pair, under different grooming algorithms. The models are quite general. We have considered heterogeneous data rates for the client traffic, arbitrary alternate routing in both logical and physical topologies, and arbitrary wavelength conversion in the optical network.

ii) Resource Planning and Logical Topology Design for Dynamic Traffic Grooming in WDM Optical Network (2004 – present)

In the literature, dynamic traffic grooming has been traditionally performed through dynamically establishing/releasing lightpaths on-demand to accommodate randomly arriving/departing client connections. Alternatively, we propose to conduct dynamic traffic grooming through designing a static logical topology a priori and routing randomly arriving/departing client connections on the designed logical topology. This approach can avoid the overhead of frequent lightpaths setup/teardown. Furthermore, for optical networks unable (or too expensive) to dynamically set up lightpaths, this approach is the only choice. We also examine logical topology design from a new perspective, different from classic logical topology design studies that focused on transport of packet traffic. Our study focuses on transport of circuit traffic (client connections), which has a coarser granularity than packet traffic. Due to the fundamental difference on client traffic nature, the design objectives and performance metrics for dynamic traffic grooming are significantly different from classic logical topology design studies.

In particular, we studied two types of problems for dynamic traffic grooming: 1) given the performance requirement and estimated client traffic demands, how to determine resources needed to meet the performance requirement in dynamic traffic grooming; 2) set up as many as possible lightpaths (a logical topology) to maximize call acceptance probability or revenue constrained by given network resource. We call the former as resource planning and the latter as logical topology design. We formulated them as integer linear programming (ILP) problems. To ensure the designed logical topology committable (i.e., all lightpaths in the logical topology can be established), the wavelength assignment is also formulated, under every wavelength conversion scenario, including no, full, sparse full, and sparse limited wavelength conversion. For large networks, we proposed two heuristic algorithms, one for each problem.

Student Supervising in Projects on Traffic Grooming

1) One graduate student, **Feng He**, studied the cross-layer path computation issue in traffic grooming and published the work in ACMSE.
   - Chunsheng Xin, **Feng He**, "Cross-Layer Path Computation for Dynamic Traffic Grooming in Mesh WDM Optical Networks," in *Proceeding of 43rd ACM Southeast (ACMSE) Conference*, Mar. 18-20, 2005, Kennesaw State University, GA.
2) Supervised one undergraduate student, Logan Shy, to develop a Traffic Grooming Demonstrator, in the School of Science and Technology STARS summer research program, summer, 2003.
3) Supervised one undergraduate student, Eddie Boon, for his senior project, "A Networking Performance Monitor", from fall 2003 to spring 2004.

B. <u>Wireless Sensor Networks</u>

Wireless sensor networks are a sensing, computing and communication infrastructure that allows us to monitor and manipulate our environment. They are a new frontier in communications. Their computation and communication infrastructure are radically different from traditional networks, and have become a popularly studied field within both industry and academic institutions, because they can potentially introduce revolutionary effect to the economy and our life, from environment monitoring, to manufacturing management, to automation in transportation and health-care industries.

i) Scalable Distributed Algorithms for Massively-Deployed Wireless Sensor Networks (2004 - present)

Recent sensor network research has concentrated on performing tasks assuming some form of centralized control. However, centralized control does not scale well to massive size networks. We design scalable distributed algorithms in massively deployed sensor networks where individual motes operate based on local information, making local decisions. We also study effective time synchronization, and in-network processing and storage in sensor networks. For time synchronization, we pursue efficient and effective peer-to-peer synchronization, where global synchronization of all nodes is not needed, and effective coordination algorithms in time synchronization of entire network. Our interest on in-network processing and storage is to design robust and effective schemes to prevent the unbalanced energy consumption among sensors, and to improve data integrity.

C. Dynamic Spectrum Access Wireless Networks

The current spectrum allocation policy for wireless communication assigns a fixed block of spectrum to each new wireless service for exclusive use. With the fast growing spectrum-based services and devices, the remaining available spectrum is being exhausted. By studies of FCC, spectrum exhaustion is actually a problem of radio access rather than a spectrum scarcity problem, because most of allocated spectrum is quiet in most of time even in very crowded downtown area of large cities. Thus the key to solving the spectrum scarcity problem is to allow dynamic access to the under-utilized spectrum, provided that the licensed users (also called primary users) of such spectrum are not interfered. The advancement in software-defined/programmable radio technology and regulatory reform in spectrum allocation policy makes it possible to dynamically scan and tune to a quiet band for communication, without interfering the licensed primary users. Like the virtual memory in operating systems to allow many processes to share the limited physical memory, dynamic spectrum access (DSA) networks enables finite spectrum to be dynamically shared among wireless devices.

i) Topology Formation in Dynamic Spectrum Access Wireless Networks (2004 -present)

A fundamental difference of DSA networks from traditional wireless networks is that there is no statically allocated fixed spectrum for use, whereas all traditional wireless networks are designed for static spectrum access that uses a certain fixed spectrum block, e.g., WLAN uses ISA bands (2.4 and 5 GHz). DSA networks use spectrum opportunity (SOP), which is a spectrum block characterized by multiple dimensions: center frequency, bandwidth, time, space, and even code (e.g., as in CDMA). This project studies a fundamental problem in DSA networks: given a set of detected spectrum bands or SOPs that can be temporarily used by each node in a DSA network, how to form a topology by selecting spectrum bands for each radio interface of each node. Each node individually detects SOPs, and the spectrum that can be used for communication might be quite different from node to node. It may not be unusual that even if every node has some (or even many) SOPs, there is still not a common spectrum among all nodes. Therefore, in DSA networks, the topology formation is significantly more challenging than in traditional wireless networks. In the topology formation, first of all, DSA network nodes need to discover SOPs. Since a SOP can be used for communication only when it is associated to a radio interface of some nodes. The second step is to associate radio interfaces of each node to SOPs available to that node, and a communication topology is formed among nodes. The routing paths between node pairs (source and destination) can then be computed on this topology, used for data transport. We proposed a novel layered graph to model the temporarily available spectrum bands, and used this layered graph model to develop effective and efficient routing and interface assignment algorithms to form near-optimal topologies for DSA networks. The numerical results showed that the layered graph approach is efficient and effective for topology formation in DSA networks.

Students Supervising in Projects on Dynamic Spectrum Access Wireless Networks

One graduate student, Bo Xie, partly performed research under my supervision in this area, published one technical paper, and presented his work in two posters.

- I.1) Co-authored the paper "A Novel Layered Graph Model for Topology Formation and Routing in Dynamic Spectrum Access Networks," in *Proceeding of First IEEE Symposium on New Frontiers in Dynamic Spectrum Access Networks (DySPAN)*, Nov 8-11, 2005, Baltimore, MD.
- I.2) Bo Xie, "Multi-channel Interface Assignment in Wireless Networks", presented in ODU-NSU Research Expo, Apr. 2005

I.3) Bo Xie, “Topology Formation in Dynamic Spectrum Access Wireless Networks”, presented in School of Science and Technology Annual Poster Session, Sep. 20, 2005, Wilder Center, Norfolk State University.

I.4) Supervised one undergraduate student, Ralph Cooke, for his senior project, “Ad hoc Vehicle to Vehicle Communication” from fall 2004 to spring 2005.