

RESEARCH STATEMENT

RESEARCH INTERESTS

My broad research interests fall within the area of optical telecommunication networks. Although I have dealt with some physical layer aspects (like dispersion and optical amplifiers), my main focus is on the networking layers. More specifically, I have performed research in mesh-connected optical network systems that carry the Wavelength Division Multiplexing (WDM) technology and the way these interact with higher networking layers such as layer 2 (e.g. Gigabit Ethernet, GigE) and layer 3 (Internet Protocol, IP). My work deals with both backbone (carrier) networks, as well as client (Metropolitan and Local Access) networks. Some of my research areas in Optical Networking can be consolidated to the following topics:

- Physical layer impairments in routing decisions in all-optical mesh-based WDM networks.
- Real-Time Automated Provisioning in Optical Networks; Routing and Wavelength Assignment (RWA).
- Traffic Grooming in IP/WDM Networks.
- Unified Control Plane for IP and Optical Network interactions.
- Provisioning signaling for both sub- and full- wavelength connections in multi-fiber WDM networks.
- Selective Protection and Restoration on a per-call basis in Optical Networks.
- Multicasting in Optical Networks.
- Network Testbed Development.
- Optical Access Networks (Ethernet Passive Optical Networks).
- Truly Native Ethernet-Based Global Multi-Service Infrastructure.

The above focus in the development of novel algorithms and signaling protocols as well as novel architecture designs that aim to allow an efficient and cost-effective operation of the currently deployed intelligent optical network systems. This work was initially part of the general research work of the Next Generation Networking Group (NGNG) at the City College (headed by Prof. M. A. Ali).

ACCOMPLISHMENTS AND ONGOING RESEARCH WORK

Automated Provisioning

My initial work focused on investigating the RWA problem that is inherent in real-time automated provisioning in WDM Networks. The investigation included both static and dynamic routing and assignment techniques and was also extended to multi-fiber environments. Since the problem is NP-hard, heuristic algorithms were developed and it was shown that considering the network status (in a dynamic and/or adaptive way) always improves the admission rate making the network more cost-effective.

Traffic Grooming and Unified Control Plane

While the wavelength channels are able to operate at speeds limited only by the current electronics capabilities (e.g. OC-192 at about 10Gbps), the traffic demands optical network operators are called to provision are generally of much lower speeds. Thus, the need for developing algorithms that efficiently pack these lower speed requests (sub-wavelength) onto the high-speed capacity of the wavelength links emerges. In the literature, this problem, also NP-hard, is generally referred to as the traffic grooming problem. In more recent work, I developed heuristics to solve the traffic-grooming problem that were both static and dynamic. However, it was always evident that current optical networking architectural trends that separated the client network's logical connectivity (already established connections) from the optical transport network's physical connectivity were imposing bottlenecks that degraded network performance.

Traditionally, the interaction between the client and carrier networks is kept to a minimum for reasons that included carrier policies and easiness in design, operation and maintenance. This means that sub-wavelength requests could be provisioned at either the client or the WDM networks independently by sequential searching for resources at each layer. My work on a unified control plane produced a novel architectural model for the emerging need of how higher layers (like IP) interact with the optical layer that is both simple and retains separation of proprietary carrier information. In work already published, a network model in which the intelligence and maintenance network functionalities are shifted down to an intelligent optical layer was proposed and evaluated.

Furthermore, the above model allows for native Ethernet frames to be transported end-to-end (over 95% of generated traffic initiates and terminates on Ethernet). We currently investigate the use of Jumbo Ethernet frames to relax encapsulation constraints and work to device ways to make the Ethernet addressing scheme suitable for adaptation in the optical backbone.

Integration Signaling

I developed and tested via simulation an integrated communication signaling framework that allows for the first time the optical network layer to provision both wavelength and sub-wavelength IP requests by combining and mixing the operations of RWA and routing over the virtual topology (existing connections). The signaling frame dictates how connections are being provisioned and released. For the first time signaling challenges associated with integration were revealed and overcome. The framework involves the building and maintaining of an identical version of the network status at geographically remote nodes without any synchronization or the presence of a centralized office. The framework has also been extended to multi-fiber links.

Integrated Protection and Restoration

As the capacities of optical networks (with multi-wavelength multi-fiber links) grow exponentially, the need for network survivability becomes intrinsic. My current work involves network survivability at the optical layer made possible on a per-call basis by our unified control plane model. The investigation deals with the devising of new algorithms as well as signaling.

Multicasting

While most of the provisioning investigated is unicast (or point-to-point), it is anticipated that real networks will need to provision multicast (point-to-multipoint) connections with applications like video conferencing. To this end, I have investigated the provisioning of multicast connections in WDM networks with partial and full light splitting capabilities. The research involved algorithms that improve performance in terms of blocking

probability and the optimum placement of splitter under various topologies. Current work is also looking into a) protecting such multicast connections with the minimum tying of extra resources, and b) the full signaling implementation of provisioning such connections (perhaps using RSVP-TE, or CR-LDP) as it seems a challenging and exciting new topic.

Ethernet Passive Optical Networks (EPONs)

The true aim of the Next Generation Internet (NGI) is to provide end-users with service that lives up to their ever-increasing bandwidth demands. To this end, I also investigated Metro- and Local-Access Networks (MAN and LAN) with special focus on Ethernet Passive Optical Network (EPON) technology. Traditionally, an EPON architecture spans a single fiber link (up to 20Km) from an Optical Line Termination (OLT) facility to a passive splitter which then distributes fiber connectivity to a number of Optical Networking Units (ONUs, or end-user facilities) with fiber links not exceeding a couple of kilometers (tree topology). The system intelligence is embedded in the OLT, which arbitrates the upstream transmissions (since the link 20Km fiber is inherently a shared medium for the ONUs). My proposal involved a decentralized approach where the ONUs communicated with each other by means of a $3 \times N$ coupler/splitter (the passive component) and arbitrated their upstream transmissions avoiding the round trip propagation delay to the OLT. The benefit of such a system is in the improvement of service quality (more specifically, data delay) since decisions on arbitration are made based on capturing a “fresher” network status. On this context, our research focuses on power limitations due to the losses at the star/coupler, synchronization issues, and compatibility with already standardized EPON protocols.

Current research on EPONs also focuses on LAN emulation by investigation of different architectures like the ring. Both centralized and decentralized models are considered, compared and contrasted. An EPON testbed to investigate our decentralized concept is also being envisaged.

Physical Layer Impairments in Routing Decisions

I am currently the project coordinator of RPF-funded project OPTISOFT which deals with the development of a software tool that can help evaluate and design Metropolitan Area Network (MAN). The basic concept is that the logical layer (i.e. routing) should observe physical limitations of the underlying physical links and nodes in deciding which resource usage optimizes network performance. Physical impairments in MANs include dispersion, optical signal-to-noise ratio (OSNR), cross-talk, amplified spontaneous emission (ASE) from amplifiers (e.g. EDFA), filter concatenation etc.

RESEARCH OUTLOOK

It is my intention to extend my IP/WDM integration framework to encompass the vision of a truly native end-to-end Ethernet network (GigE/WDM networking paradigm). To this end I have already started preliminary research with some publications. The issues arising, like the MAC addressing, the routing under the Spanning Tree Protocol etc. consist exciting research areas to achieve this goal.

I am also planning to work on new networking problems, such as the security problem in all-optical networks using quantum encryption. The usage of such networks is rapidly growing in fields such as e-commerce and banking, which makes the issue of secure networks extremely timely and critical. This problem is especially important in WDM-

based networks, where the high data bit rates purport that even a short attacks will cause the compromise of a large amount of data.

It is important to note that I intend to extend my research to other telecommunication areas like wireless and sensor networks. For example, and with respect to EPON networks, wireless communication between ONUs seems to be a solution that further enhances network performance and provides for added protection. Another interesting research topic which gains ground nowadays is wireless optics whereby optical network speeds are reaching end-users via photodiodes installed at high-rise rooftops.

Finally, I find it imperative to balance the work between scientific research and the development of tools for practical applications. My goal is to actively perform scientific research and at the same time, work on the development of practical technologies through industrial collaborations and visiting researchers.