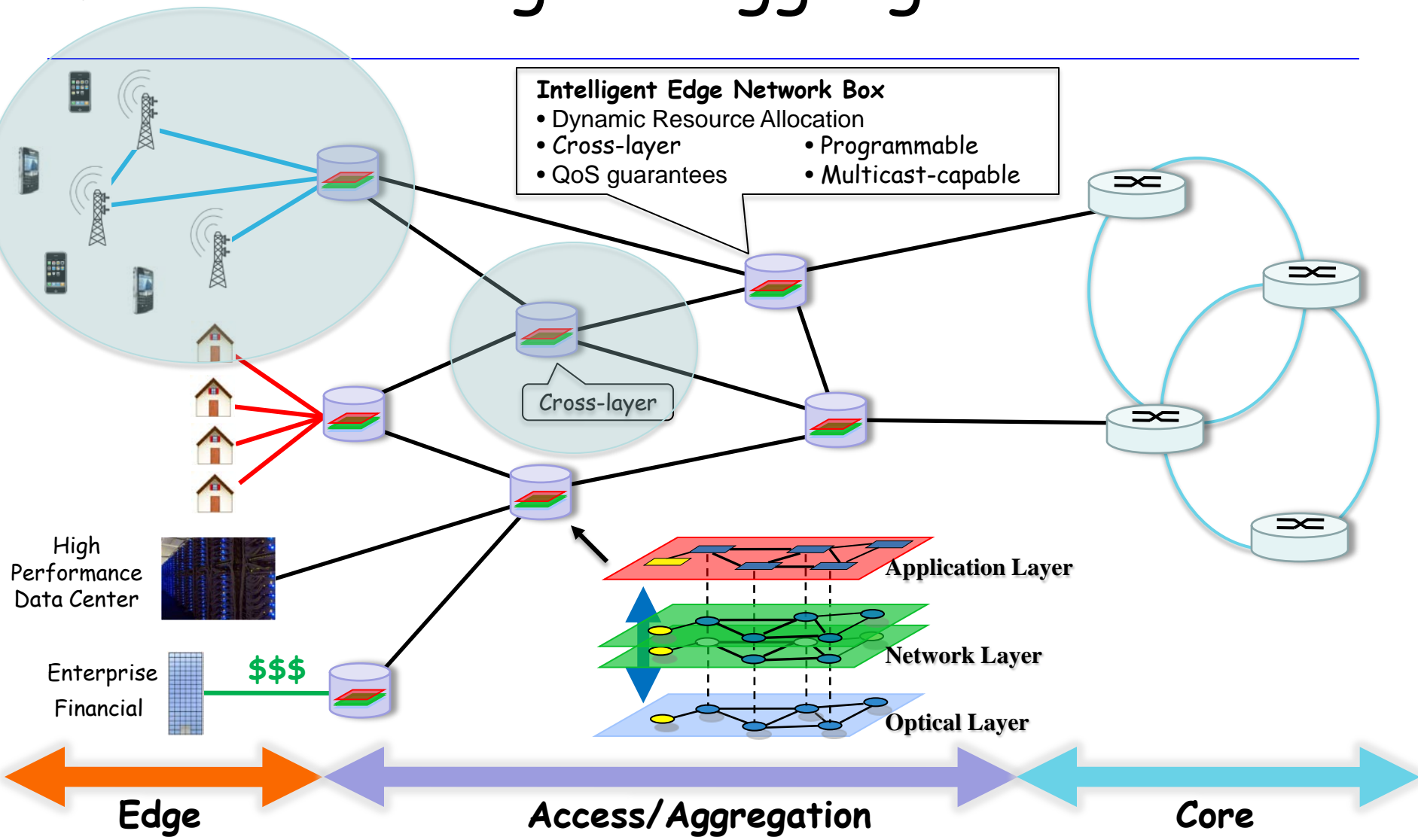


Cross Layer Interactions between Wireless, IP, and Optical Access/Aggregation Networks

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Department of Electrical Engineering
Columbia University

WG II: Intelligent Aggregation Network

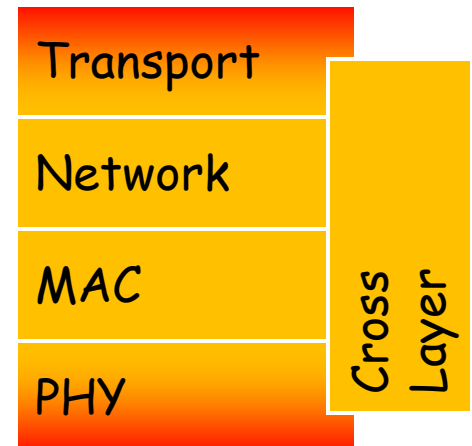


Wireless Backhauling - Problem Statement...

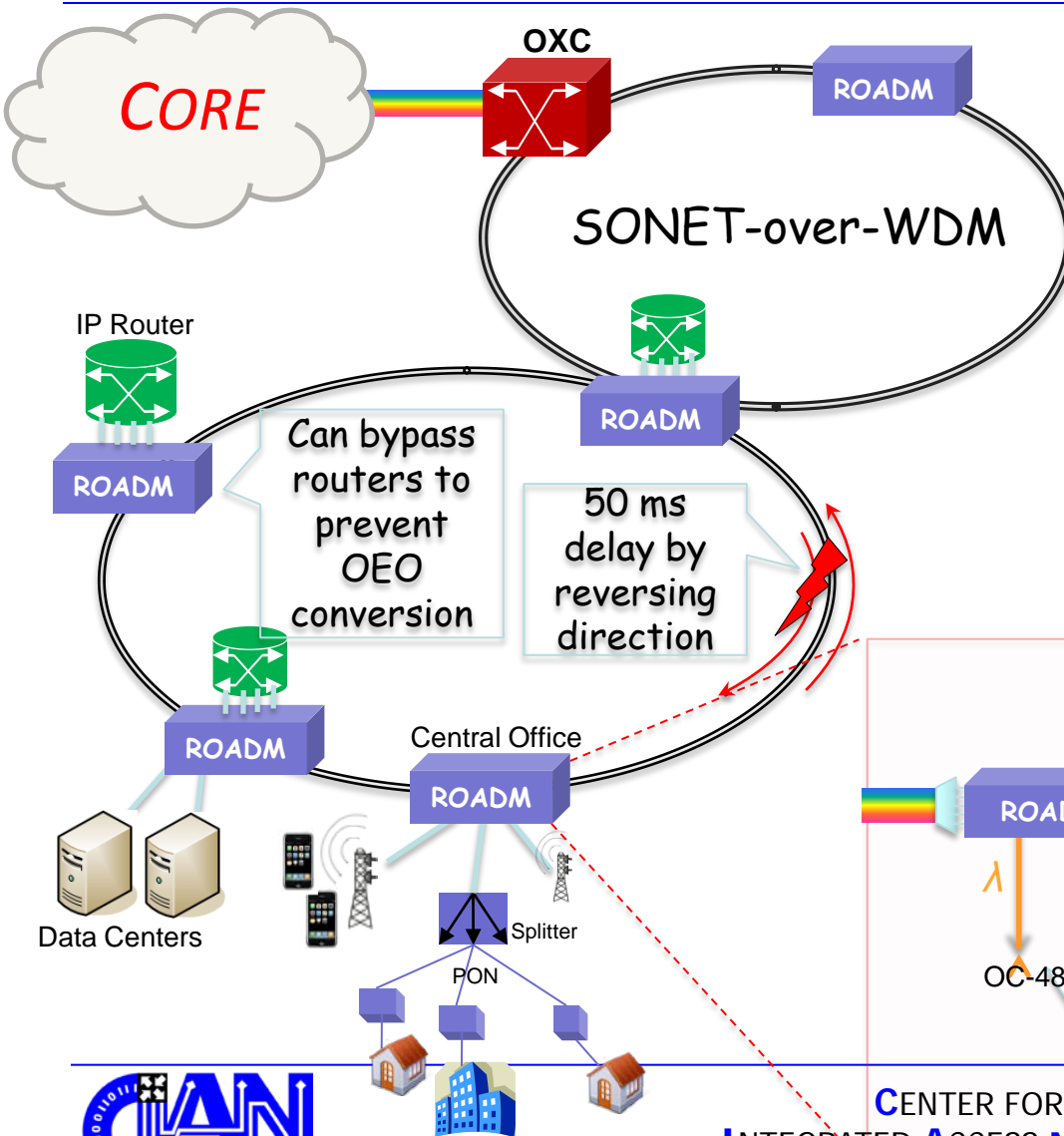


Project Objectives

- Design cross layer interfaces between wireless and optical access/aggregation networks
- Leverage methods developed for wireless cross layering to develop IP-over-Optical algorithms
 - Develop real-time algorithms for improving **energy-efficiency** in optical aggregation networks
- Construct a wireless-optical testbed



Metro Networks - Current State



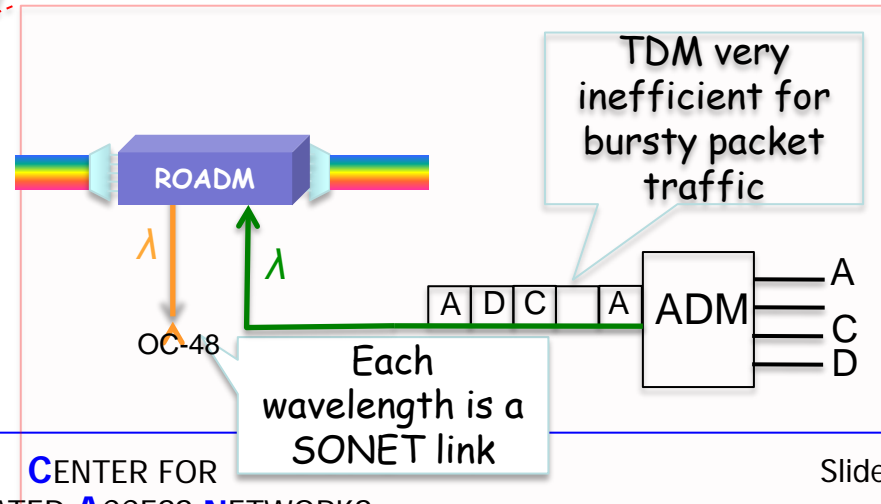
SONET rings over WDM

Advantages:

- 50 ms restoration
- DWDM allows many SONET links on one fiber

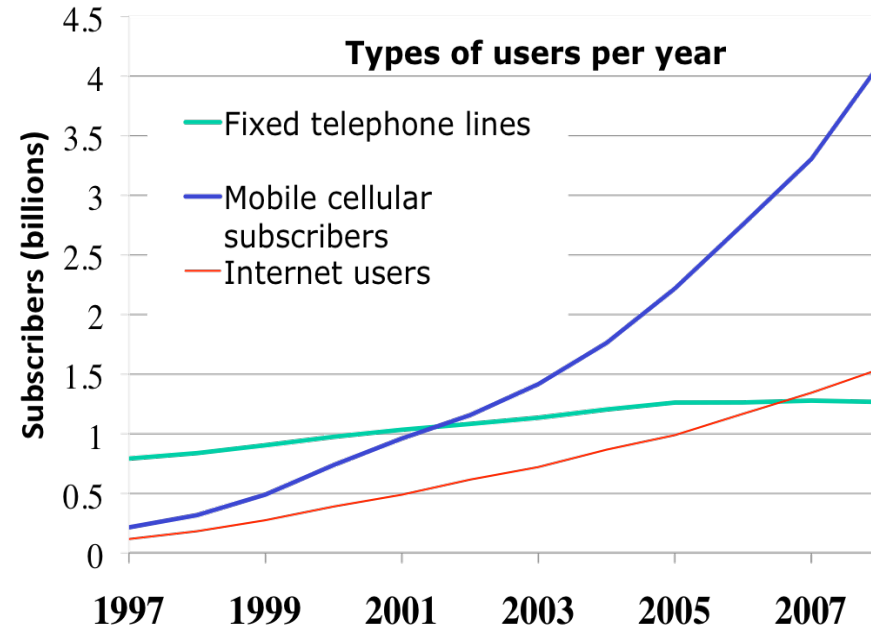
Disadvantages:


- Designed for synchronous (non-bursty) traffic
- To reconfigure, must change all TDMs
- Metro gap: 1GbE → 2.4 Gbps

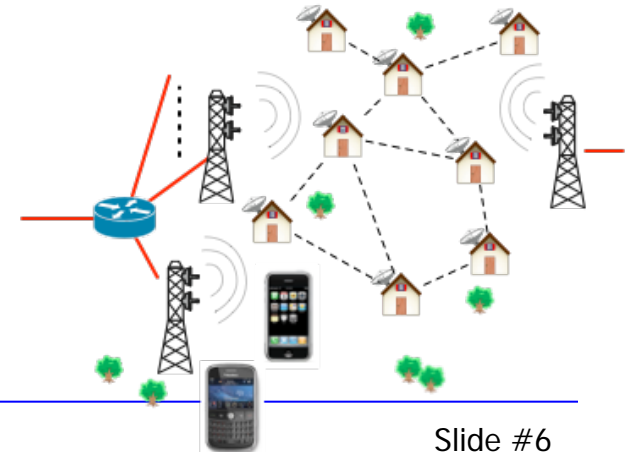


Wireless Backhauling

- Wireless networks will generate a lot of traffic to/from the edge and substantial backhaul traffic
 - By 2017 - 7 trillion wireless devices
 - 60% yearly traffic increase
 - AT&T's traffic increased 50 times in first 3 "iPhone years"

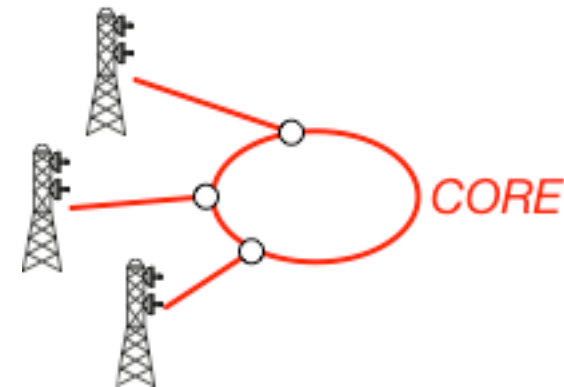


- Long Term Evolution 
 - Deployments starting in 2011
 - Peak download rate of 326.4 Mbit/s
 - Nearby base stations connected in a mesh
- LTE Advanced - 4G

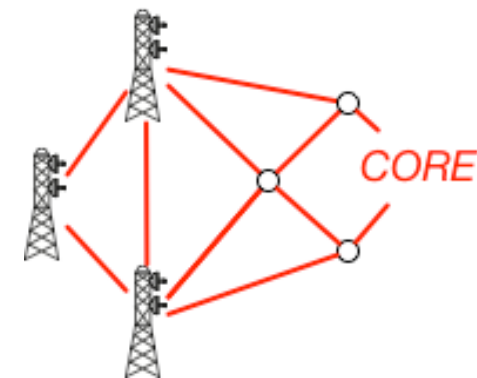


Changing Backhaul Architecture

- Previously, base stations connected by a tree
 - Easy to implement using legacy technologies

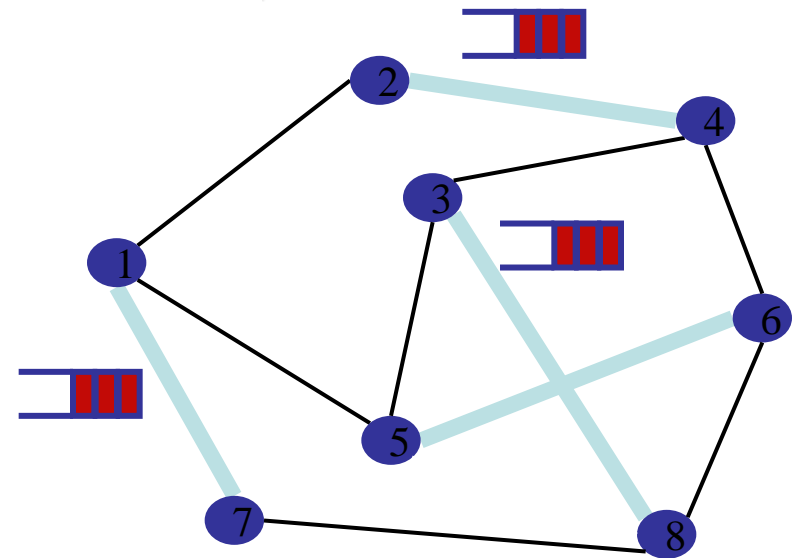


- In LTE and 4G, base stations will form a mesh
 - Mesh structure and carrier Ethernet adds complexity
 - **Energy consumption** of the base stations and switches/routers is becoming very important
 - **Lower layer information** can be used to make decisions **dynamically**

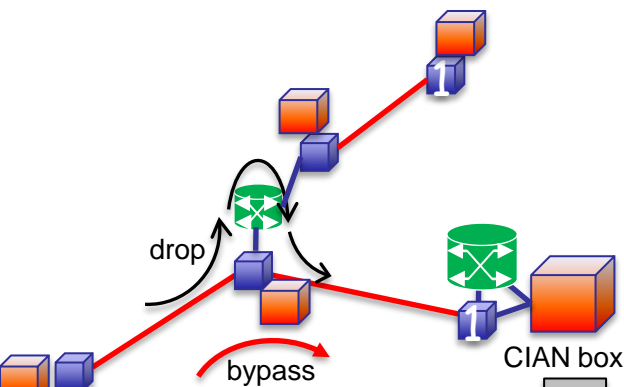


Convergence of IP and Optical Networks

- Developing algorithms that will leverage information from the physical layer and physical layer programmability in making higher layer resource allocation
- Energy efficiency
 - Apply some of the energy-efficient algorithms developed for wireless networks
- Real-time BER measurements
 - Make decisions regarding routing, flow control, QoS
 - Well-established theory: **"Network Utility Maximization"**
- WDM links may suffer from cross-talk
 - Similar to wireless interference
 - → Choose switch schedule or modulation scheme based on link quality



Energy Optimization via Dynamic Bypass



Minimize energy by bypassing:

- processing in switches
- regenerators

$$\min \sum E_{\text{router}} w + \sum E_{\text{reg}} w_r$$

subject to $\sum \text{delay} \leq \text{Delay_Guarantee}$

$\prod \text{reliability} \geq \text{Reliability_Guarantee}$

$\text{BER}_i(t) \leq \text{BER_Guarantee}$

Routing matrix

$\text{Demand}(t) \leq \text{Lightpath_Capacity}$

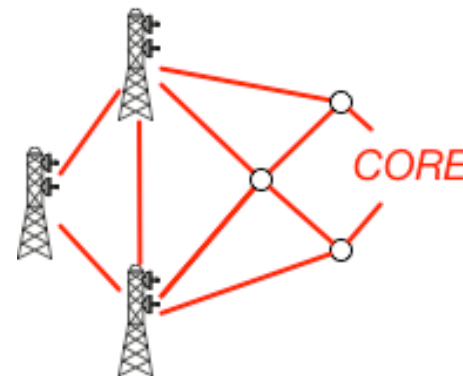
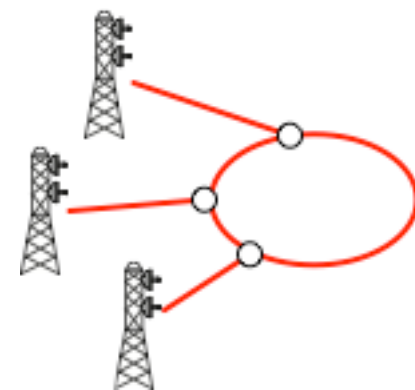
Using the CIAN-box

- Measure the effect of bypasses in real-time
- Use accurate metrics in the next optimization iteration
- Solve distributedly

Customers' Service Level Agreement (SLA) guarantees must be met at all times

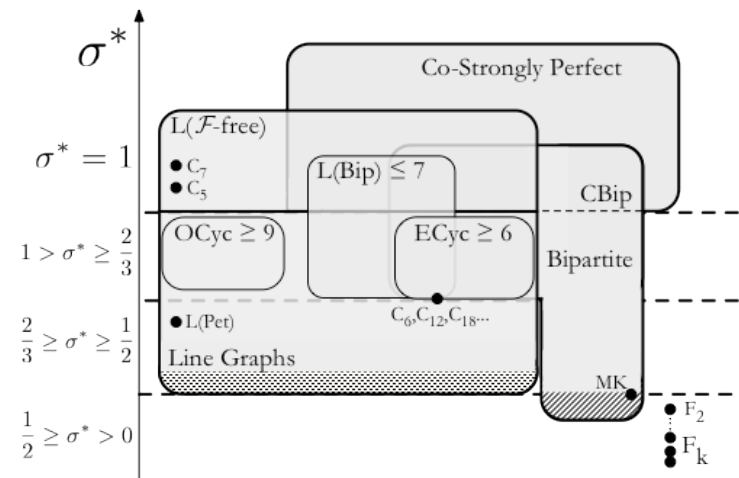
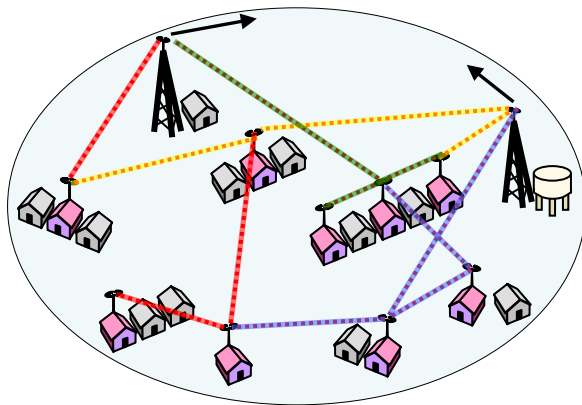
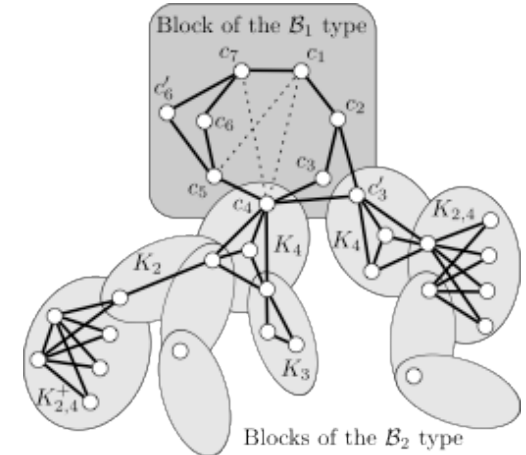
Changing Backhaul Architecture

- Mesh structure poses challenges and opportunities
- Nodes will have to select base stations
 - [Jagannathan, Menache, Modiano, and **Zussman**, Columbia Technical Report, July 2010]
- Dynamic Spectrum Access Systems
 - [Coffman, Roberts, Simatos, Tarumi, and **Zussman**, ACM SIGMETRICS, June 2010]
- Fast and efficient algorithms are required
 - Both in the wireless network and in the switches
 - [Bianco, **Hay**, and Neri, **Best paper** in IEEE GLOBECOM 2009, to appear in IEEE/ACM Trans. Networking]
 - [**Birand**, Chudnovsky, Ries, Seymour, **Zussman**, and Zwols, IEEE INFOCOM, Mar. 2010, to appear in IEEE/ACM Trans. Networking]



Analyzing the Performance of Distributed Algorithms

- Characterize all network graphs in which simple scheduling algorithms are optimal
 - Identify candidate topologies to be used in the aggregation network
- Characterize families of graphs under general interference models according to their achievable performance



Wireless-Optical Testbed

- Wireless-Optical testbed is being developed
 - Collaboration with the **Lightwave Research Lab** (Lai, Wang, Bergman)
 - Wireless Mesh - 802.11 stations
 - Infiniband used for interfacing between the wireless nodes and the optical switch
 - Will be used for evaluating our cross-layer algorithms

