ENSC 835: High-Performance Networks
Spring 2008

Implementation of a Multi-Channel Multi-Interface Ad-Hoc Wireless Network

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Final Project Presentation
School of Engineering Science
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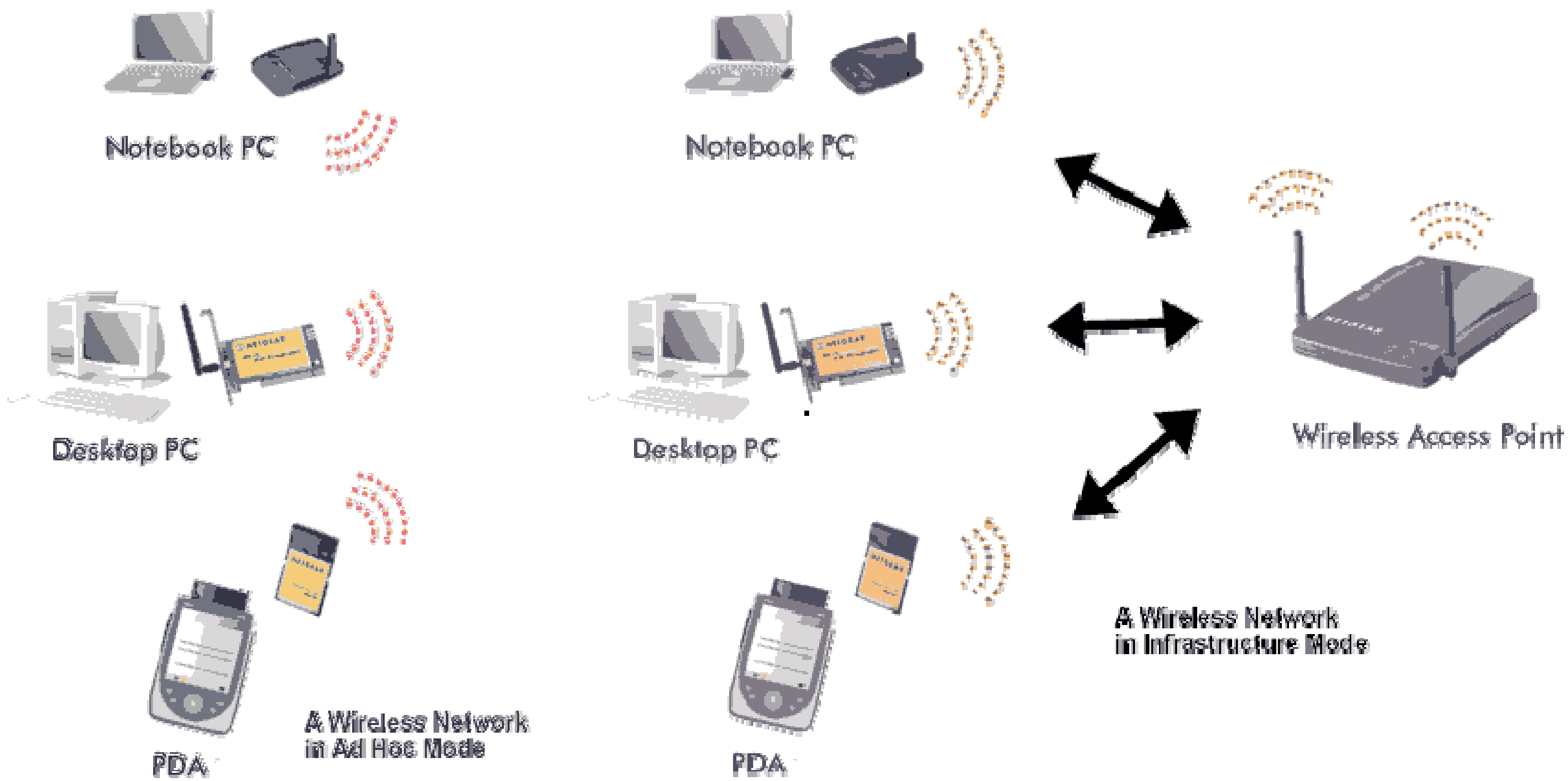
Roadmap

- Introduction
- Motivation
- Related Work
- Project Scope
- Interface Switching
- Adding Multiple Interface Support to ns-2
- Simulation
- Shortcomings and Future Work
- Conclusion
- References

Introduction

- Wireless Local Area Networks (WLANs) have recently become popular
  - mobility and connectivity within a broad coverage area
- More electronic devices now come pre-equipped with a wireless interface, e.g. cell phones, laptops, PDAs, etc.
  - reduced wireless hardware costs
  - the throughput demand has increased
- IEEE 802.11 is a popular set of standards for wireless networks
  - 802.11a/b/g/n
  - endpoint devices (or nodes) can be operated in 2 modes:
    - infrastructure
    - ad-Hoc (will be the focus of the project)

Introduction: Infrastructure vs. Ad-Hoc



From: “Selecting Between Infrastructure and Ad Hoc Wireless Modes,” http://kbserver.netgear.com/kb_web_files/N101519.asp.

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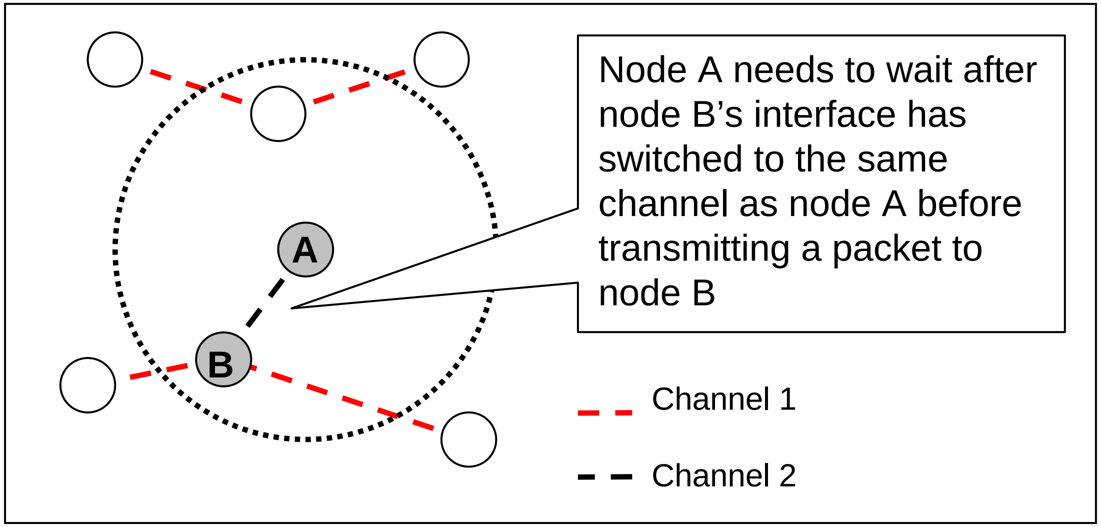
Motivation: Background

- IEEE 802.11 has defined multiple non-overlapping (non-interfering) channels in 2.4 GHz and 5 GHz
  - e.g. 802.11b/g operating in the 2.4 GHz bands have 3 non-overlapping channels (1, 6, 11) for use in Canada and the US
- Multiple channels have been used in infrastructure-based wireless networks
  - by assigning different channels to adjacent access points
  - node has an ability to switch between channels
- But, ad-hoc wireless networks are typically configured to use only a single channel
  - to ensure connectivity of all their nodes
  - the aggregate bandwidth provided by the available radio spectrums is not fully-utilized

Motivation: Multiple Channels Single Interface

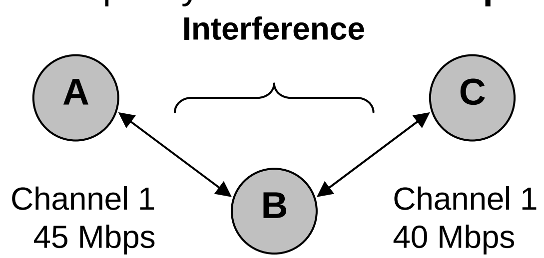
- Two adjacent nodes can communicate with each other if they have one interface on a common channel
- In an ad-hoc network with several nodes, if each node has multiple channels, but only one interface
  - packets may be delayed at some nodes if their next hops are not on the same channel



Motivation: Single Channel Multiple Interfaces

- Suppose each node has multiple interfaces, what if assigning all of them to be on the same channel?
  - transmissions on consecutive nodes could interfere with each other, still degrading the overall throughput

Channel Capacity = **100 Mbps**
All of nodes A, B, and C are using **Channel 1**
Link Capacity = 100/2 = **50 Mbps**

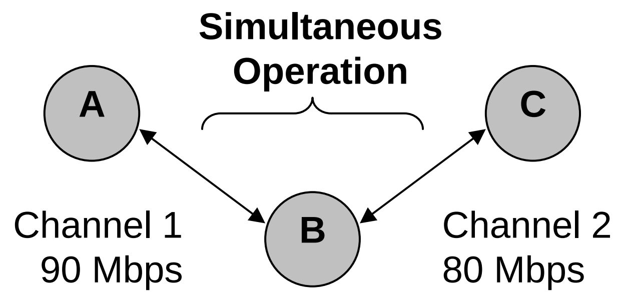


Combined Throughput = **85 Mbps**

Motivation: Solution

- Using multiple interfaces, a node is able to transmit and receive data simultaneously
  - cannot be done with only one interface, as it is half-duplex
- With multiple interfaces and multiple channels:
  - one interface is transmitting data on one channel, while the other interface is receiving data on another channel
- The overall achievable throughput can be improved

Channel Capacity = **100 Mbps**
Node A uses **Different Channels** to communicate with node B and C
Link Capacity = **100 Mbps**



Combined Throughput = **170 Mbps**

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Related Work

- Interface switching and multi-channel routing (MCR) [2]
  - chosen implementation for this project
- Centralized channel assignment and routing [3]
  - for use in static networks where traffic is directed towards specific gateway nodes
    - any node to communicate with any others in [2]
  - expects stationary nodes and traffic load on every link
    - not required by [2] to assign interfaces and compute routes

[2] P. Kyasanur and N. H. Vaidya, "Routing and Link-layer Protocols for Multi-Channel Multi-Interface Ad Hoc Wireless Networks," SIGMOBILE Mobile Computing and Communications Review, vol. 10, no. 1, pp. 31-43, Jan. 2006.

[3] A. Raniwala, K. Gopalan, and T. Chiueh, "Centralized Channel Assignment and Routing Algorithms for Multi-Channel Wireless Mesh Networks," *Mobile Computing and Communications Review (MC2R) 2004*, vol. 8, no. 2, pp. 50-65, Apr. 2004.

Related Work

- New MAC layer protocols [4], [5]
  - both require changes to the existing IEEE 802.11 standard
    - the idea in [2] can run over existing IEEE 802.11 interfaces
- Slotted Seeded Channel Hopping (SSCH) [6]
  - a link-layer solution that uses a single interface and can run over unmodified IEEE 802.11
  - however, SSCH does not support multiple interfaces

[4] S. Wu, C. Lin, Y. Tseng, and J. Sheu, "A New Multi-Channel MAC Protocol with On-Demand Channel Assignment for Multi-Hop Mobile Ad Hoc Networks," *International Symposium on Parallel Architectures, Algorithms and Networks (ISPAN), 2000*, Dallas, TX, pp. 232-237, Dec. 2000.

[5] R. Maheshwari, H. Gupta, and S. R. Das, "Multichannel MAC Protocols for Wireless Networks," *Sensor and Ad Hoc Communications and Networks (SECON) 2006*, Reston, VA, vol. 2, pp. 393-401, Sept. 2006.

[6] P. Bahl, R. Chandra, and J. Dunagan, "SSCH: Slotted Seeded Channel Hopping for Capacity Improvement in IEEE 802.11 Ad-Hoc Wireless Networks," *ACM Annual International Conference on Mobile Computing and Networking (MobiCom) 2004*, Philadelphia, PA, pp. 216-230, Oct. 2004.

Related Work

- Weighted Cumulative Expected Transmission Time (WCETT) [7]
  - assumes the number of interfaces per node is equal to the number of channels

- Therefore, the scheme in [2] is more flexible
  - the number of available interfaces can be less than the number of channels
    - equipping a node with one interface per channel is expensive
    - can be implemented over existing 802.11 devices

[7] R. Draves, J. Padhye, and B. Zill, “Routing in Multi- Radio, Multi-Hop Wireless Mesh Networks,” ACM Annual International Conference on Mobile Computing and Networking (MobiCom) 2004, Philadelphia, PA, pp. 114-128, Oct. 2004.

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Project Scope

- Paper [2] consists of 2 parts:
  - an interface assignment strategy using the technique of interface switching
    - simplifies coordination among nodes while utilizing multiple available channels
  - an Multi-Channel Routing (MCR) protocol
    - selects routes with the highest throughput by accounting for channel diversity and interface switching cost
- For the scope of this project,
  - we only implement and evaluate the first part in the Network Simulator (ns-2)

Project Scope

- We extend ns-2 to support multiple channels and multiple interfaces by referring to the guideline in [1]
  - modify ns-2's MobileNode library to support multiple interfaces
  - still preserve the legacy operations of IEEE 802.11 interfaces
- We implement the interface switching algorithm proposed in [2]
  - since MCR will not be implemented, we incorporate interface switching in the existing AODV routing agent in ns-2

AODV – Ad-hoc On-demand Distance Vector

Reactive routing protocol; establishes a route to a destination only on demand

[1] R. A. Calvo and J. P. Campo, "Adding Multiple Interface Support in NS-2," University of Cantabria, Jan. 2007.

[2] P. Kyasanur and N. H. Vaidya, "Routing and Link-layer Protocols for Multi-Channel Multi-Interface Ad Hoc Wireless Networks," SIGMOBILE Mobile Computing and Communications Review, vol. 10, no. 1, pp. 31-43, Jan. 2006.

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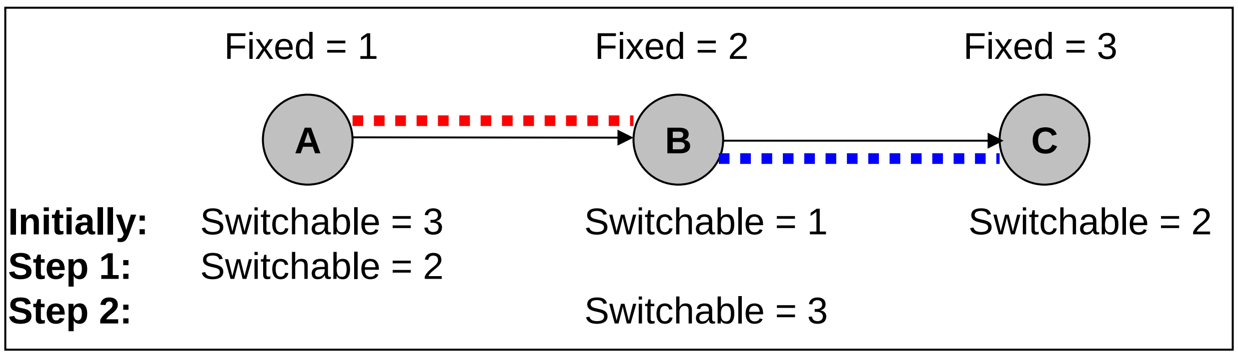
Interface Switching

- To maximize the utilization of all available channels, interfaces have to be switched from one to another
  - switching protocol [2]
- Each node has *M* interfaces of two types:
  - Fixed Interface
    - *K* of the *M* interfaces are assigned to some *K* channels → fixed channels
    - used to receive data
  - Switchable Interface
    - *M*-*K* interfaces are assigned to any of *M*-*K* channels → switchable channels
    - enables node X to transmit to node Y by switching to the fixed channel used by Y

Interface Switching: Example

- $M = 2$ and $K = 1$ for all nodes (one fixed and one switchable) and 3 non-overlapping channels
- The routing path is A → B → C
  - node A wants to send a packet to node C



- The sender adapts to the receiver by changing its switchable interface to the receiver's fixed interface

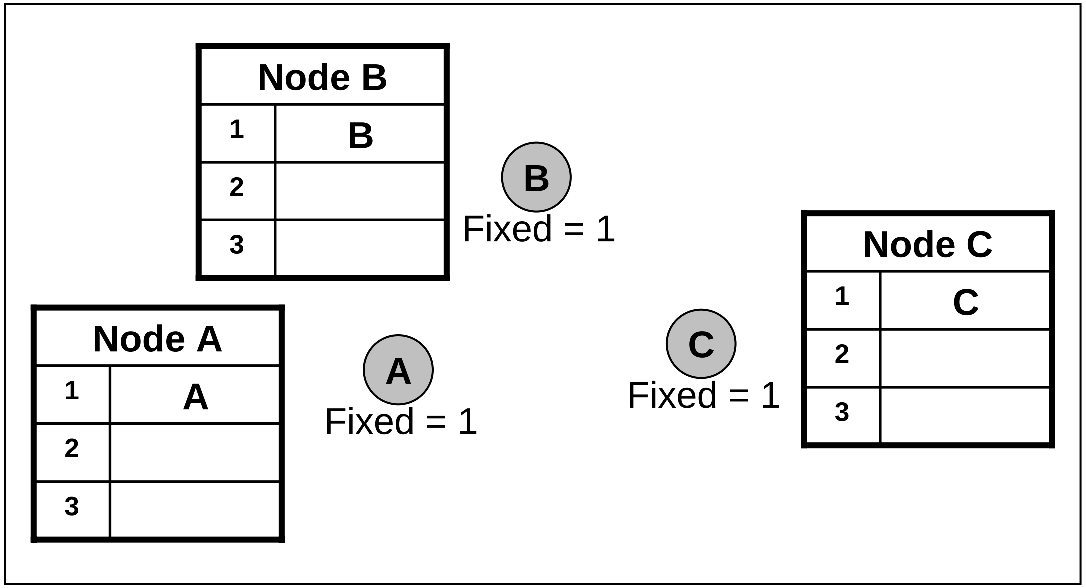
From: [2] P. Kyasanur and N. H. Vaidya, "Routing and Link-layer Protocols for Multi-Channel Multi-Interface Ad Hoc Wireless Networks," SIGMOBILE Mobile Computing and Communications Review, vol. 10, no. 1, pp. 31-43, Jan. 2006.

Fixed Interface Assignment

- A localized algorithm with goals:
  - to choose the channel to be assigned to a fixed interface
  - to inform the neighbour nodes about the channel being used by the fixed interface
- Each node maintains two tables:
  - NeighbourTable (NT)
    - contains the fixed channels being used by its neighbours
  - ChannelUsageList (CUL)
    - keeps the number of nodes using each channel as their fixed channel

Fixed Interface Assignment

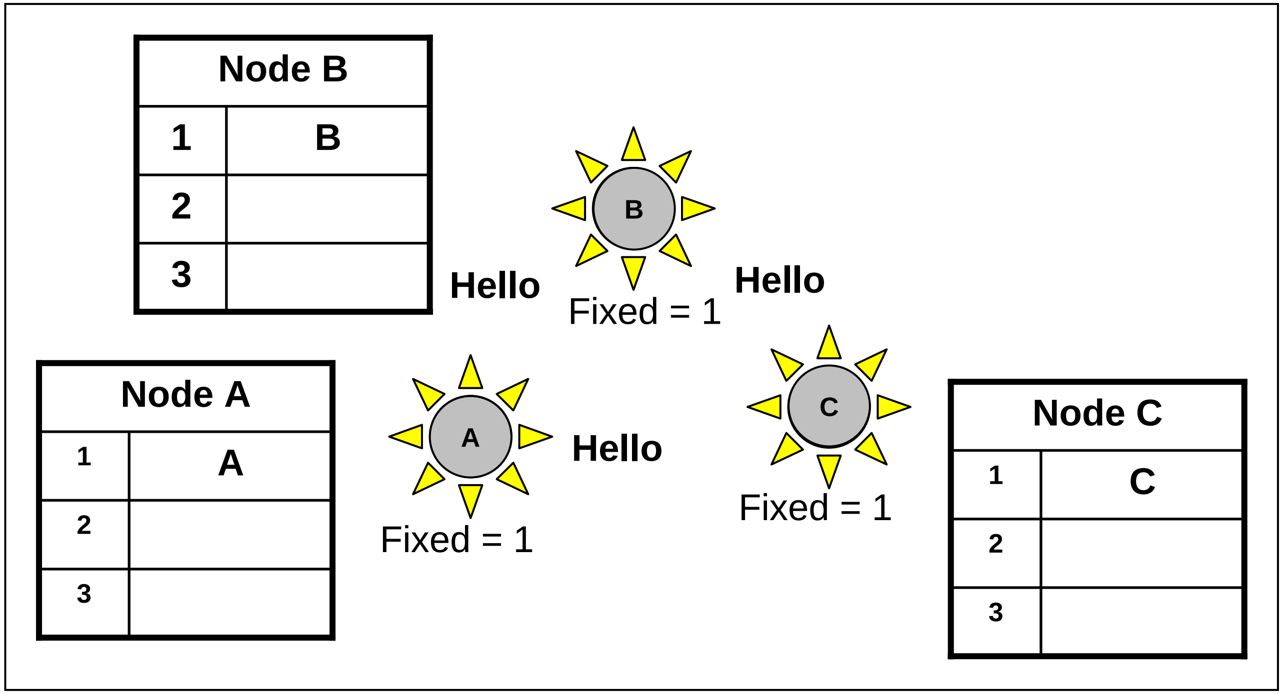
- Initially, each node chooses a random channel for its fixed interface



* We will present the node's table as an implicit combination of NT and CUL

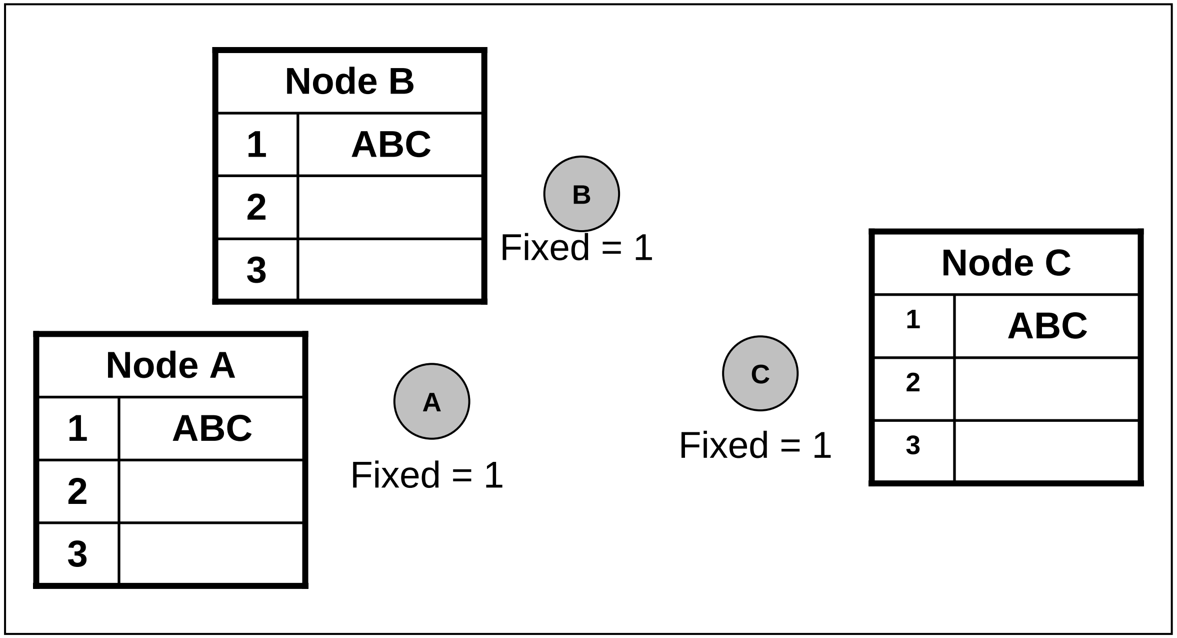
Fixed Interface Assignment

- Periodically, each node broadcasts a Hello packet on every channel
  - contains the fixed channel used by the node



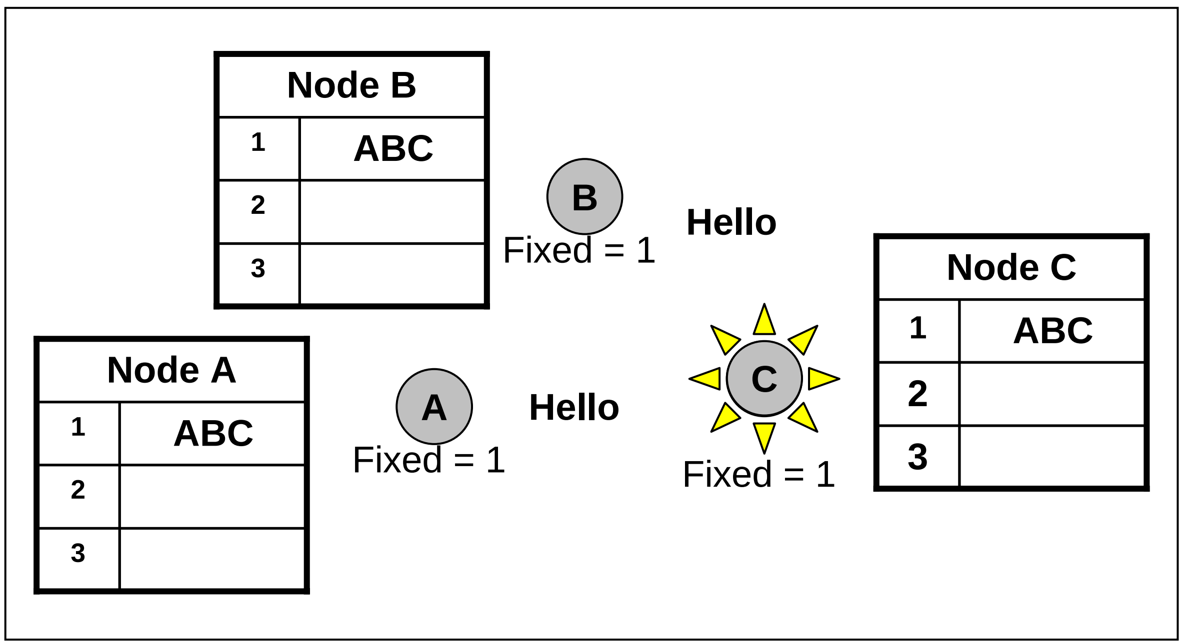
Fixed Interface Assignment

- When a node receives a Hello packet from a neighbour, it updates:
  - NT with the fixed channel of that neighbour
  - CUL using the NT of its neighbour



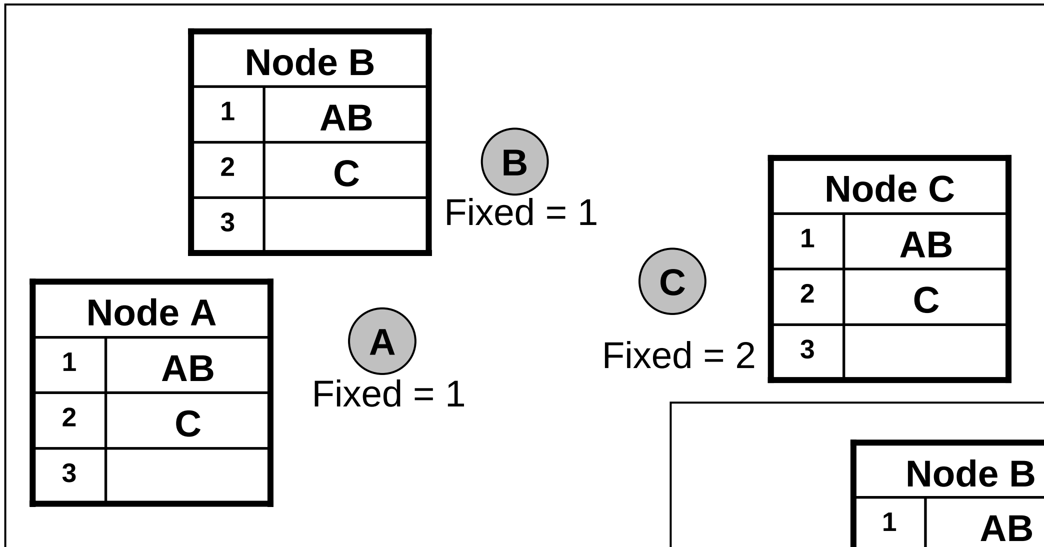
Fixed Interface Assignment

- Each node periodically consults its CUL
  - if the number of other nodes using the same fixed channel as itself is large, then a node with probability p = 0.4 changes its fixed channel to a less used channel



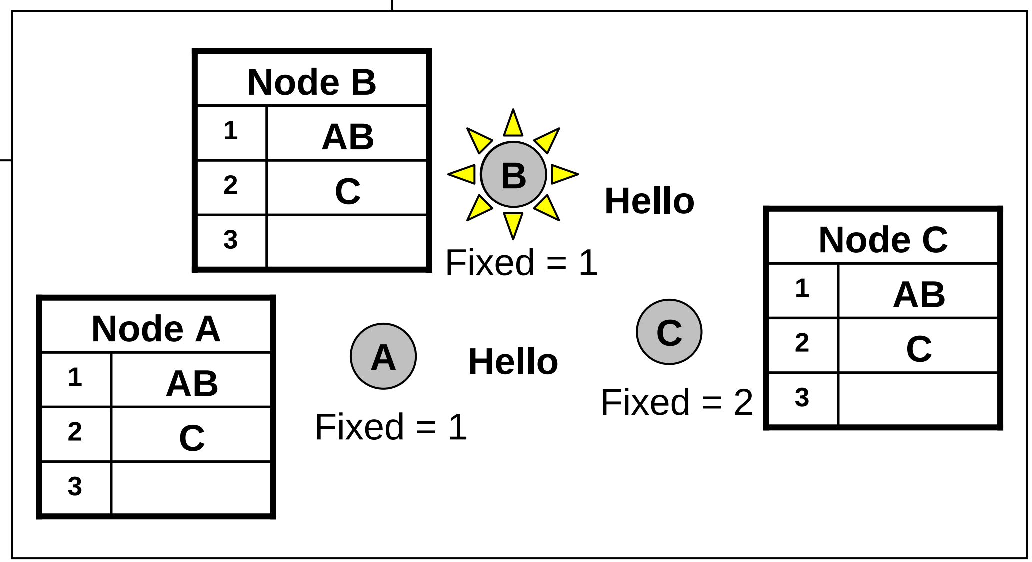
a. Suppose Node C wants to change to Channel 2, it broadcasts to its neighbour

Fixed Interface Assignment

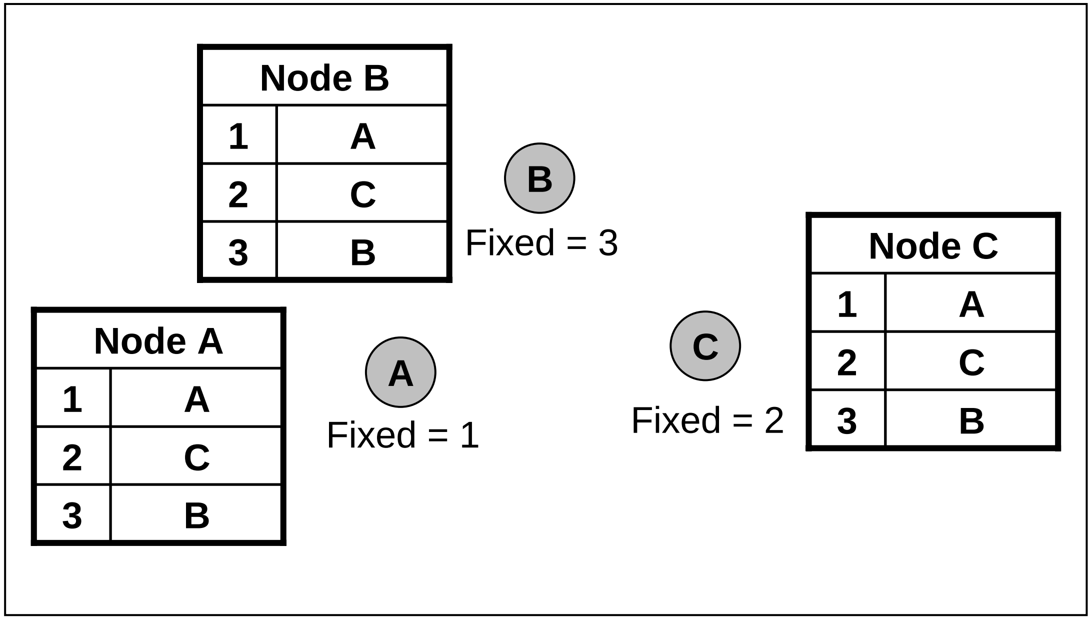


b. After the broadcast, node C's fixed interface switches to Channel 2 and each node's CUL gets updated.

c. Suppose Node B wants to change to Channel 3, it broadcasts to its neighbour



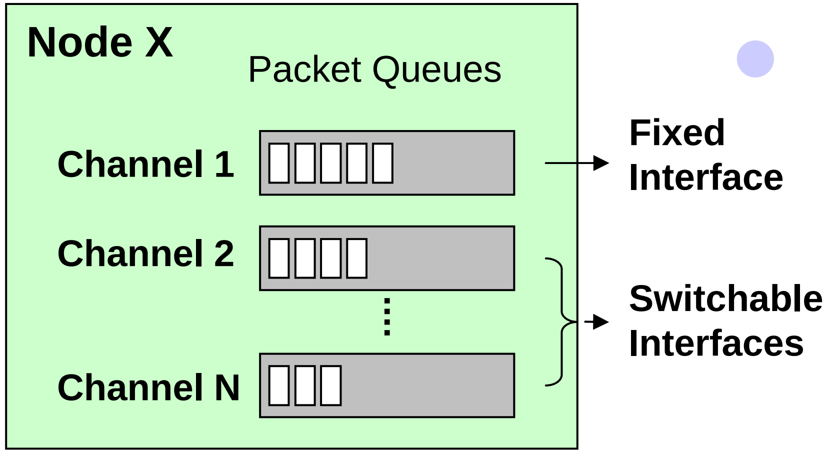
Fixed Interface Assignment



d. After the broadcast, node B's fixed interface switches to Channel 3 and each node's CUL gets updated.

Switchable Interface Assignment

- Each node maintains a packet queue for each channel:



- When a packet is received,
  - if the sender has the same fixed channel as the receiver, enqueue to the fixed channel
  - otherwise, enqueue to the switchable channel
  - for broadcast, add to each queue
- Changes channels only if there are packets queued for another channel

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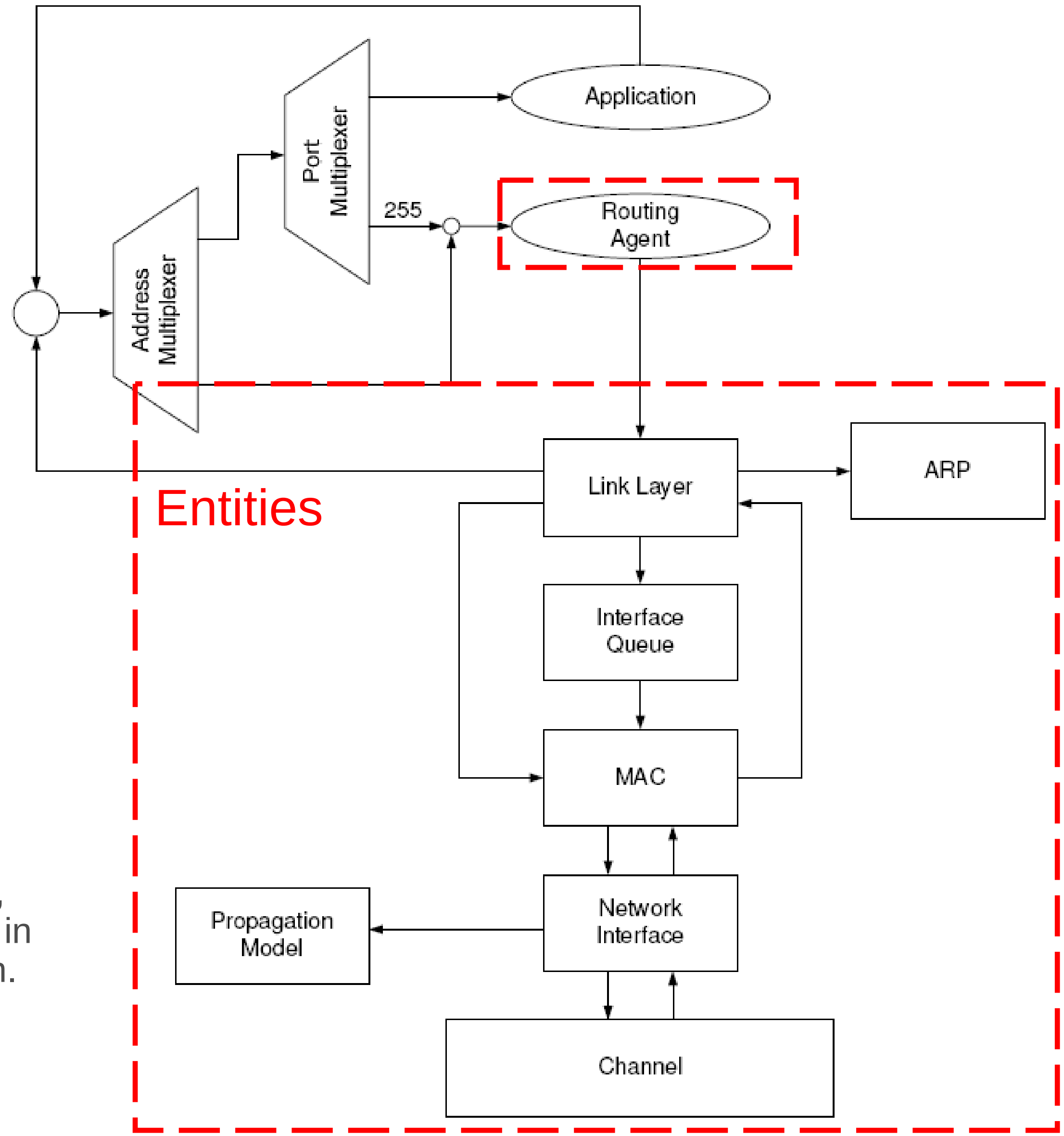
Adding Multi-Interface Support to NS-2

- ns-2.32 (latest as of the project) does not support this feature
- We incorporate the approach from guideline [1] because it allows:
  - changeable number of channels
  - variable number of interfaces per node
    - can be less than the number of channels
  - each node to be connected to different number of channels
  - preservation of NS-2's legacy operation
    - implies no functional changes to 802.11

[1] R. A. Calvo and J. P. Campo, "Adding Multiple Interface Support in NS-2," University of Cantabria, Jan. 2007.

Original *MobileNode*

- We modify NS-2's existing MobileNode model
  - an extension of the Node object in NS-2 with additional functionalities like mobility, ability to transmit and receive on a channel



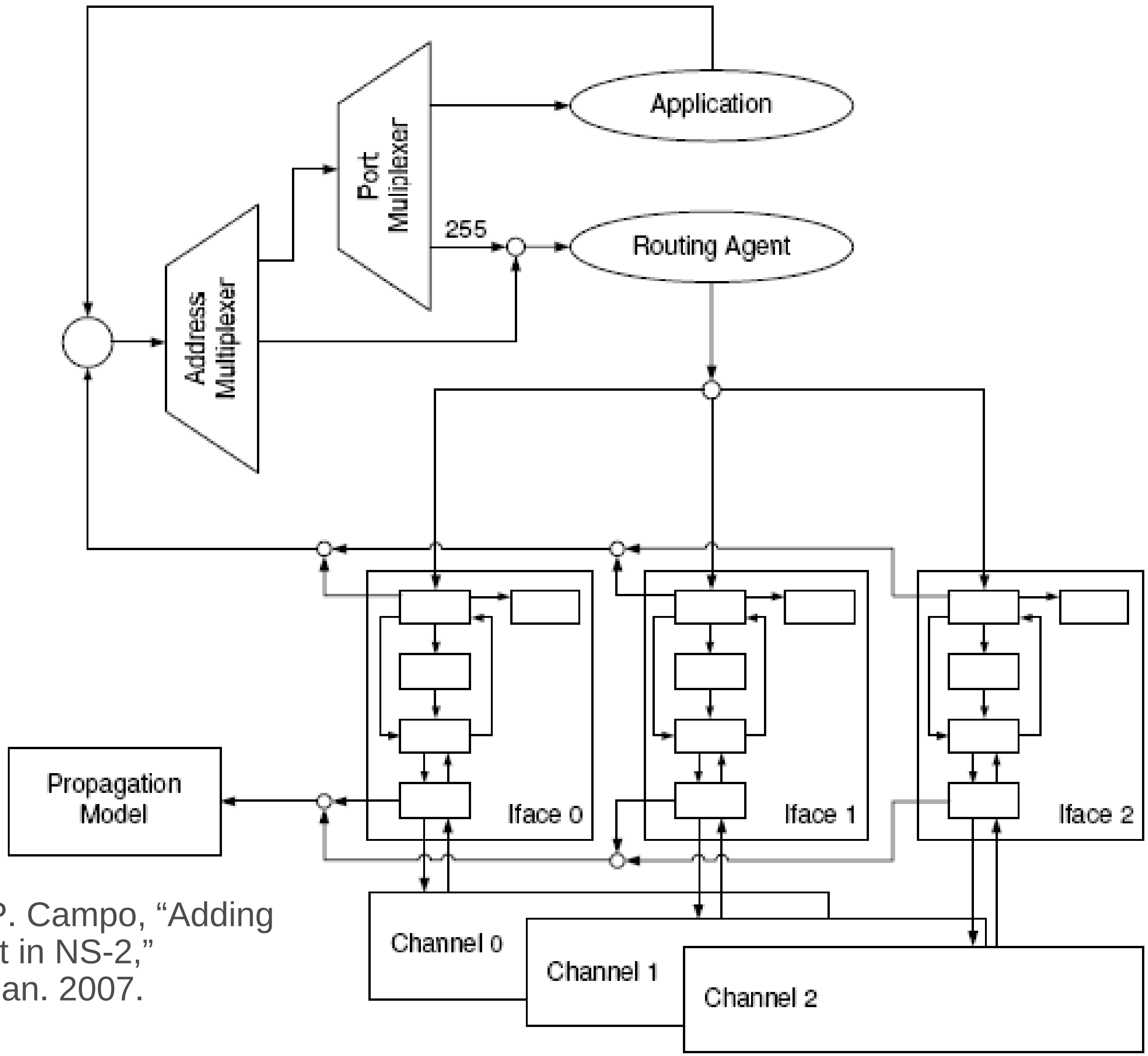
From: [1] R. A. Calvo and J. P. Campo, "Adding Multiple Interface Support in NS-2," University of Cantabria, Jan. 2007.

Original *MobileNode*

- MobileNode consists of:
  - Routing Agent, e.g. the AODV in our project
    - routes data packets to the next-hop node on the MobileNode's behalf
  - Link Layer, Address Resolution Protocol (ARP)
    - sets the MAC destination address in the MAC packet header
    - resolves the associated hardware address and insert the packet into the interface queue
  - Interface Queue
    - gives priority to the stored routing protocol packets
  - Media Access Control (MAC)
    - processes data packets received from or to be sent to the link layer
  - Network Interface
    - serves as a hardware interface for MobileNode to access the channel
  - Channel
    - simulates the effect of the real wireless channel on the transmitted signal

Modified *MobileNode*

- After modifications:
  - each node can have as many instances of the link layer, ARP, interface queue, MAC, network interface and channel entities as the number of interfaces



From: [1] R. A. Calvo and J. P. Campo, “Adding Multiple Interface Support in NS-2,” University of Cantabria, Jan. 2007.

Modified *MobileNode*

- Each instance of the entities is an interface
  - essentially just allows multiple instances to co-exist
    - no modifications to 802.11
- Incoming traffic arrives through the corresponding channel and travel through the various entities in ascending order
- For outgoing traffic, selecting which interface to pass the data packets is handled by the routing agent
  - challenge: how to select the appropriate interface?
    - AODV + Interface switching from [2]

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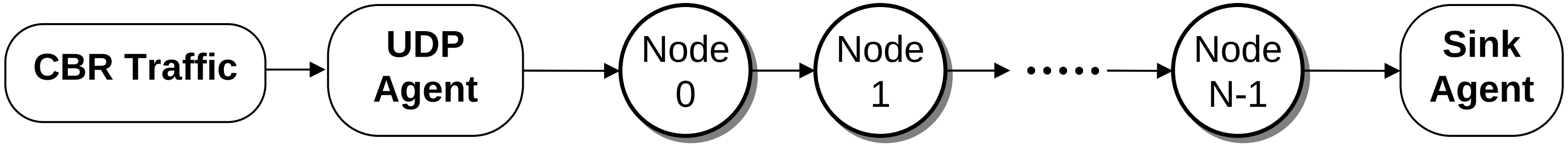
Simulation: Configuration

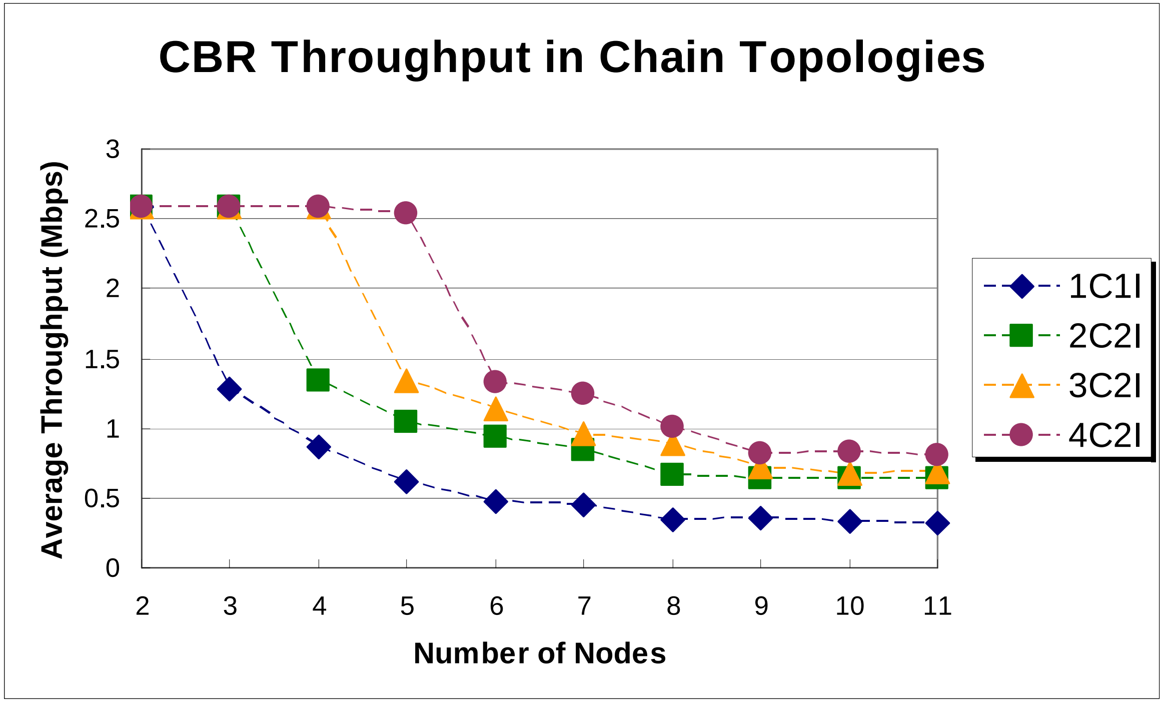
- Using the modified ns-2:
  - test the effectiveness of interface switching and throughput
    - routing is not tested as MCR is not implemented



- Scenario:
  - simple chain topologies of 2-11 stationary nodes (single route)
  - simulation duration: 60 s (actual simulation time is slightly longer)
  - channel capacity: 5.4 Mbps
  - constant bit-rate (CBR) traffic flow from the first node to the last node of the chain
    - transmitted over UDP (no flow and congestion controls)
    - 1000 bytes per packet, sent every 1.4 ms
  - 2 interfaces per node (1 fixed, 1 switchable)

Simulation: Results

- The average throughput while varying the number of channels, n → nC2I
  - compare with a single channel single interface network



Simulation: Observations

- The throughput of 1C1I networks degrades by half or more as the number of nodes increases by 1 each time
  - intermediate nodes cannot send and receive data at the same time
  - interference within the carrier sense range
- Higher throughput with multiple channels and 2 interfaces on each node
  - interface switching assigns the fixed channel of successive nodes to different channels
  - intermediate nodes can send data to the next node using its switchable interface, while receiving data on its fixed interface
- Fewer throughput improvement when the number of nodes > number of channels + 1
  - some nodes will be on some common channels → interference
  - however, still higher than the case of 1C1I

Shortcomings and Future Work

- Merely the **interface switching** solution implemented is not sufficient
  - the routing protocol may select routes wherein successive nodes interfere with each other
  - the AODV typically selects the shortest path
    - may not utilize all the available channels
- Should implement the MCR as a new ad-hoc routing agent in ns-2
  - capable of selecting high-throughput routes
  - can evaluate the performance in random topologies

Conclusion

- We have learned, implemented, and simulated a multi-channel multi-interfaces ad-hoc wireless networks using ns-2
  - modified ns-2's MobileNode to add the support for multiple interfaces
  - added interface switching to ns-2's AODV agent
- Having multiple interfaces on a node allows adjacent nodes to communicate in parallel on multiple channels
  - simulation results demonstrates that the achievable network throughput improves

References

- [1] R. A. Calvo and J. P. Campo, "Adding Multiple Interface Support in NS-2," University of Cantabria, Jan. 2007.
- [2] P. Kyasanur and N. H. Vaidya, "Routing and Link-layer Protocols for Multi-Channel Multi-Interface Ad Hoc Wireless Networks," SIGMOBILE Mobile Computing and Communications Review, vol. 10, no. 1, pp. 31-43, Jan. 2006.
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References

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- [7] R. Draves, J. Padhye, and B. Zill, "Routing in Multi- Radio, Multi-Hop Wireless Mesh Networks," *ACM Annual International Conference on Mobile Computing and Networking (MobiCom) 2004*, Philadelphia, PA, pp. 114-128, Oct. 2004.
- [8] C. Perkins, et. al., "Ad hoc On-Demand Distance Vector (AODV) Routing," RFC 3561, *Network Working Group*, The Internet Society, Jul. 2003.

Thank You!

Questions?