

# Research Direction Introduction



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# Outline

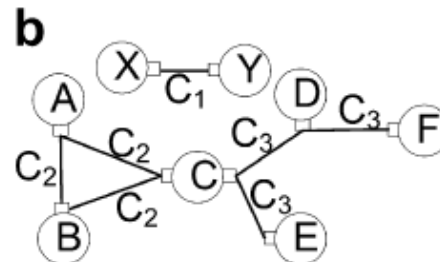
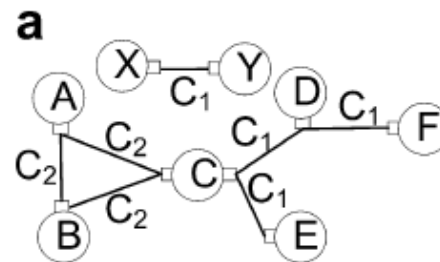
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- ▶ **Background**
  - ▶ Channel Assignment Criteria
  - ▶ IEEE 802.11s
- ▶ **Related Works**
- ▶ **Problem Description**
- ▶ **Future Reading**

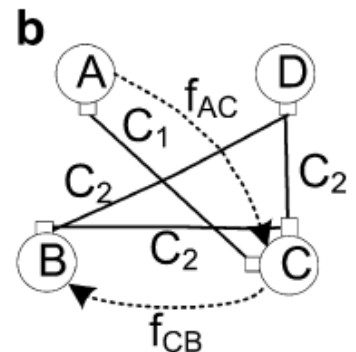
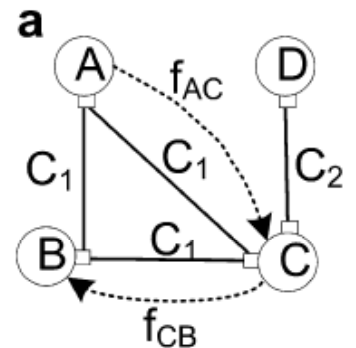
# Background

- ▶ Background about WMNs and Channel assignment is told....
- ▶ Channel Assignment Classification [1]
  - ▶ Interference-aware
    - ▶ External and internal
  - ▶ Load-aware
    - ▶ Concurrent traffic loads
    - ▶ Link traffic loads
  - ▶ However, it is hard to synchronize....

Interference-aware



Load-aware



[1] J. Crichigno, M.-Y. Wu and W. Shu, "Protocol and architecture for channel assignment in wireless mesh networks", *Ad Hoc Networks* Volume 6, Issue 7, Pages 1051-1077, September 2008.

# Background

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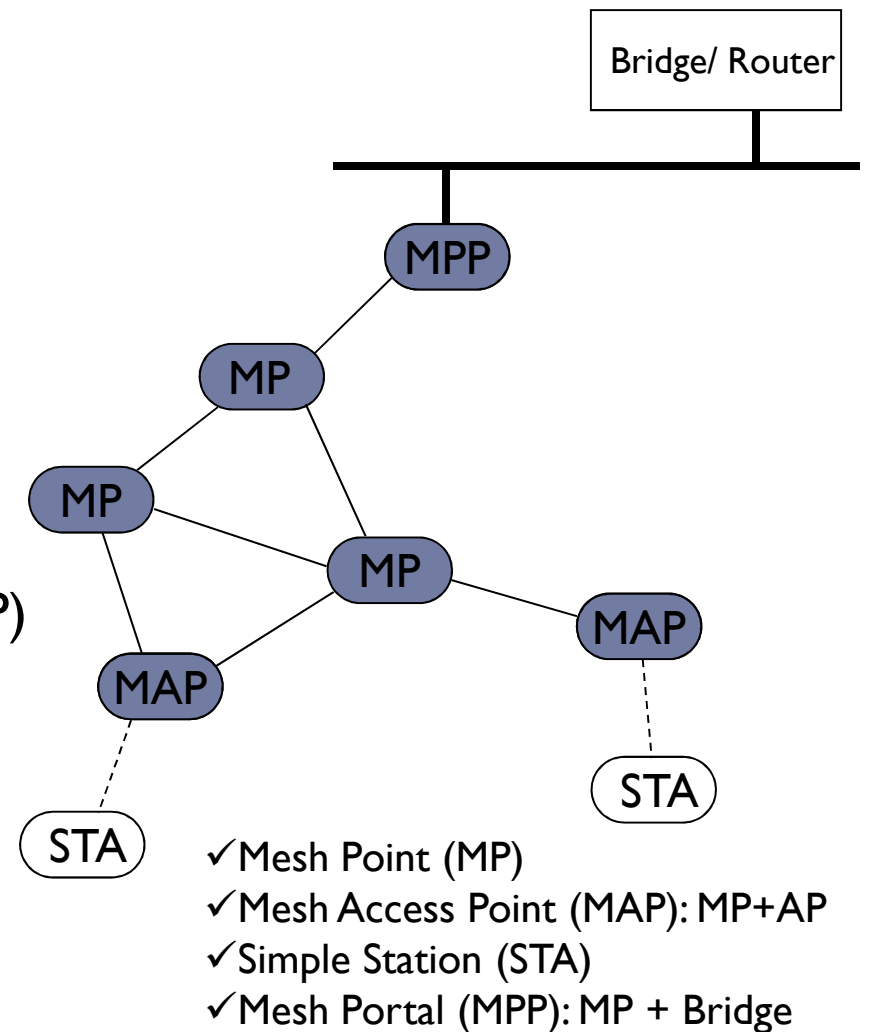
- ▶ IEEE 802.11s ( draft )
  - ▶ Last version published on Mar 2009
  - ▶ For mesh networking

Frame Formats
Mesh Security
Mesh Coordinated Channel Access (MCCA)
Mesh Discovery and Peering Management
Mesh Peering Management
Mesh Channel Selection
Mesh Path Selection, Forwarding, and Interworking
Intra-Mesh Congestion Control
Mesh Beaconing and Synchronization
Power Management in a Mesh BSS

Source: IEEE 802.11 Standard (<http://ieeexplore.ieee.org/servlet/opac?punumber=5154155>)

# Background

- ▶ IEEE 802.11s ( draft )
  - ▶ Boot Sequence of a mesh point
    - 1) Neighbor discovery
    - 2) Channel selection
    - 3) Link establishment
    - 4) Local link state measurement
    - 5) Path selection initialization
    - 6) AP initialization (optional – if MAP)



# Background

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- ▶ Two directions after discovering background:
  - ▶ IEEE 802.11 MAC protocol in WMNs
    - ▶ Proposed MAC protocols
  - ▶ Channel Assignment in WMNs
    - ▶ Dynamic, Quasi or Static channel assignment
    - ▶ Multi-radio

# Proposed MAC Protocol[7]

TABLE I. CHARACTERISTICS OF MULTI-CHANNEL MAC PROTOCOLS

Protocols	Medium Access	Transceiver	Dedicated Control Channel	Synchronous
SSCH	Channel Hopping	Single	No	Yes
MMAC	CSMA/CA	Single	Yes	Yes
Li et al	CSMA/CA	Single	Yes	No
DPC	CSMA/CA	Multiple	Yes	No
Jain et al	CSMA/CA	Multiple	Yes	No
DCA	CSMA/CA	Two	Yes	No
CHMA	Channel Hopping	Single	No	Yes
ODC	CSMA/CA	Single	No	No
McMAC	Channel Hopping	Single	No	Yes
CAM-MAC	CSMA/CA	Single	Yes	No
RICH-DP	Channel Hopping	Single	Yes	Yes
PSM-MMAC	CSMA/CA	Multiple	Yes	Yes
PCAM	CSMA/CA	Three	No	No
FMC-MAC	CSMA/CA	Single	Yes	Yes

[7] H.Wang, H. Zhou and H. Qin, "Overview of Multi-channel MAC Protocols in Wireless Networks", International Conference on Wireless Communications, Networking and Mobile Computing, October 2008.



# Background

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- ▶ Two directions after discovering background:
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    - ▶ Proposed MAC protocols
  - ▶ Channel Assignment in WMNs
    - ▶ Dynamic, Quasi or Static channel assignment
    - ▶ Multi-radio



## Related Work[2]

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- ▶ **[2]Wireless mesh networks: a survey**
  - ▶ Ian F.Akyildiz, Xudong Wang, Weilin Wang
  - ▶ *Computer Networks, Volume 47, Issue 4, Pages 445-487*
  - ▶ March, 2005
  
- ▶ A detailed study on advances and open research issues in WMNs in 2005.

# Related Work[2]

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- ▶ Critical factors influencing network performance for WMNs:
  - ▶ Radio techniques
    - Reconfigurable radios, software radios
  - ▶ Scalability
    - The end-to-end reliability sharply drops
    - Distributed architecture is hard to be synchronized
  - ▶ Broadband and QoS
    - Delay, fairness, aggregate and per node throughput, packet loss ratio

# Related Works[2]

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- ▶ Introduction in each OSI-layer
  - ▶ MAC layer's design issue for WMNs
    - Multi-hop communication
    - Distributed and multi-point to multi-point
    - Self-organization: the knowledge of the network topology
    - Mobility
- ▶ open research issue:
  - ▶ Multi-channel Multi-radio MAC
    - H. Yu, P. Mohapatra and X. Liu, "Channel assignment and link scheduling in multi-radio multi-channel wireless mesh networks", *Mobile Network and Applications, Volume 13, issue 1-2*, Apr. 2008.
    - A. P. Subramanian, H. Gupta and S. R. Das, "Minimum Interference Channel Assignment in Multi-radio WMNs", *IEEE transactions on mobile computing*, Dec. 2008.
  - ▶ more QoS metrics

## Related Works[2]

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- ▶ **What's in it for me?**
  - ▶ Understanding the concept about WMNs
  - ▶ Multi-channel Multi-radio MAC
  - ▶ QoS metrics, such as delay/ throughput, fairness

## Related Works[3]

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- ▶ **[3]IEEE 802.11 MAC protocol over wireless mesh networks: problems and perspectives**
  - ▶ Tzu-Jane Tsai and Ju-Wei Chen
  - ▶ *International conference on Advanced Information Networking and Applications*
  - ▶ March, 2005
- ▶ The related key technologies of WMNs, including the problem and challenge of the enhanced MAC protocol.

# Related Works[3]

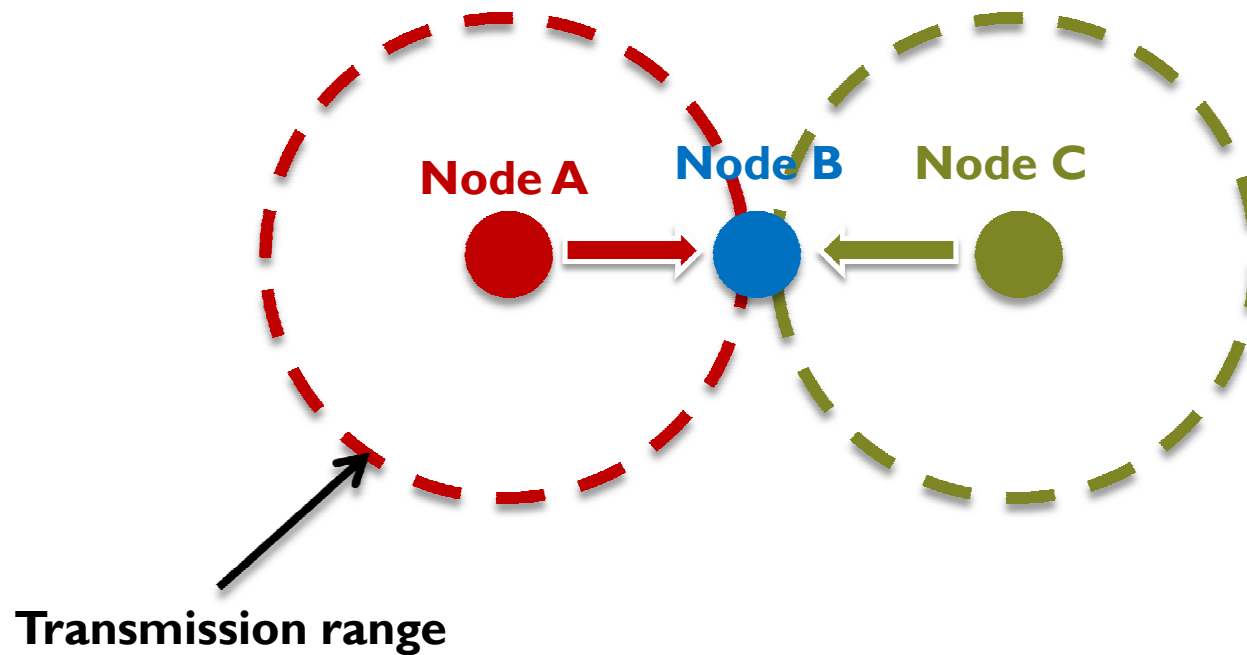
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- ▶ The performance of IEEE 802.11 MAC protocol isn't satisfactory due to:
  - ▶ Hidden terminal problem: multi-channel
  - ▶ Exposed terminal problem : multi-channel
- ▶ Conclusion
  - ▶ It is necessary to establish at least one path with enough bandwidth before the transmission is triggered
  - ▶ Multi-channel ?

# Hidden Terminal Problem

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▶ Scenario:



# Related Works[3]

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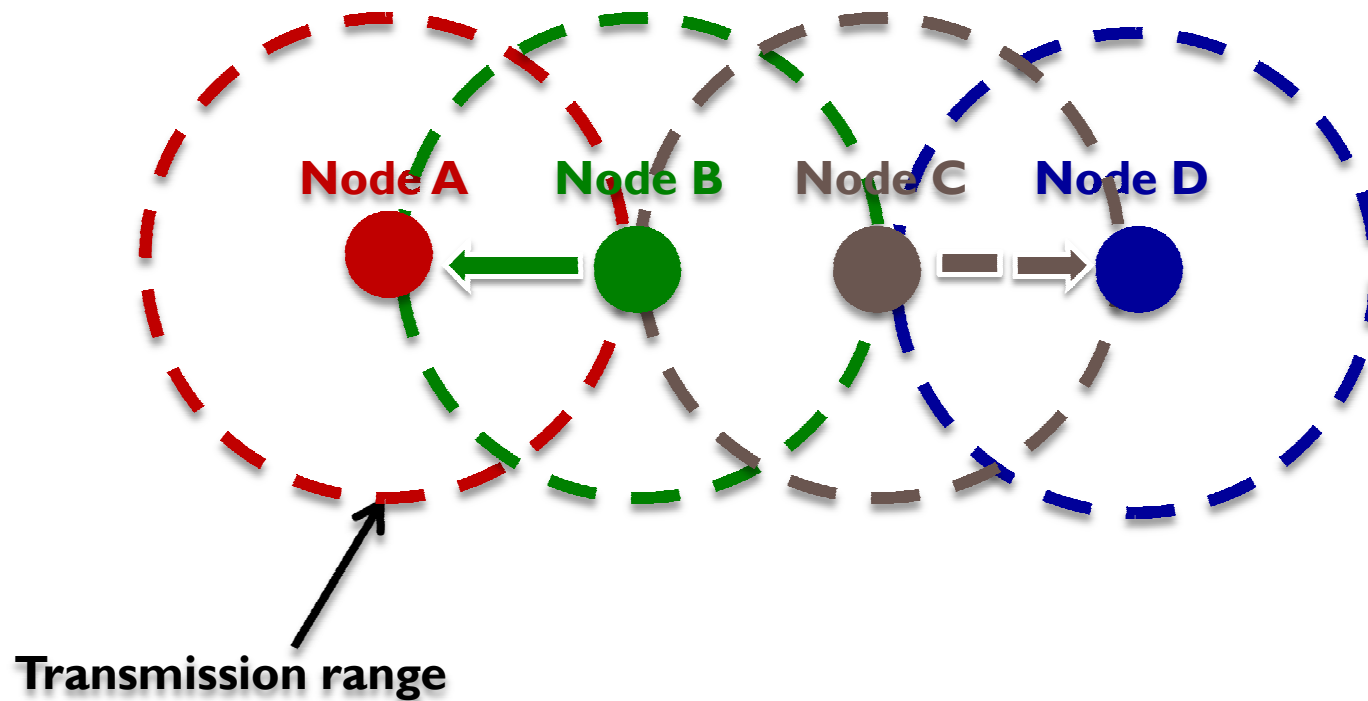
- ▶ The performance of IEEE 802.11 MAC protocol isn't satisfactory due to:
  - ▶ Hidden terminal problem: multi-channel
  - ▶ Exposed terminal problem : multi-channel
- ▶ Conclusion
  - ▶ It is necessary to establish at least one path with enough bandwidth before the transmission is triggered
  - ▶ Multi-channel ?



# Exposed Terminal Problem

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► Scenario:



# Related Works[3]

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- ▶ The performance of IEEE 802.11 MAC protocol isn't satisfactory due to:
  - ▶ Hidden terminal problem: multi-channel
  - ▶ Exposed terminal problem : multi-channel
- ▶ Conclusion
  - ▶ It is necessary to establish at least one path with enough bandwidth before the transmission is triggered
  - ▶ Multi-channel ?

## Related Works[3]

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- ▶ What's in it for me?
  - ▶ By designing a multi-channel MAC protocol, it can solve “Hidden terminal problem” and “Exposed terminal problem”.
  - ▶ Divide channels to two difference kinds:
    - ▶ For control
    - ▶ For data transmission

## Related Works[4]

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- ▶ **[4] Interference-Aware Channel Assignment in Multi-Radio Wireless Mesh Networks**
  - ▶ K. N. Ramachandran, E. M. Belding, K. C. Almeroth and M. M. Buddhikot
  - ▶ INFOCOM
  - ▶ April, 2006
- ▶ An interference-aware channel assignment algorithm and protocol for multi-radio wireless mesh networks.

# Related Works[4]

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- ▶ Contributions
  - ▶ A multi-radio conflict graph to model the interference relationship
  - ▶ A novel interference estimation scheme for routers
  - ▶ Dynamic , interference-aware channel assignment algorithm ( BFS-CA ) that minimizes interference
  - ▶ A link redirection protocol to prevent the disruption of flows

## Related Works[4]

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- ▶ **What's in it for me?**
  - ▶ With interference-awareness to model a multi-channel multi-radio WMNs
  - ▶ Multi-radio conflict graph
  - ▶ Local or global information to help estimate interference level on each router
  - ▶ The procedure to model dynamic channel assignment in interference-aware

## Related Works[5]

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- ▶ **[5]A Near-Optimal Distributed QoS Constrained Routing Algorithm for Multichannel WMMs**
  - ▶ 謝友仁
  - ▶ July, 2009
- ▶ With a simple channel assignment heuristic algorithm, the thesis propose a distributed QoS constrained routing algorithm to increase capacity both in system perspective and user perspective.

## Related Works[5]

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- ▶ **What's in it for me?**
  - ▶ Combine various MAC protocol with dynamic channel assignment to form a cross-layer scenario
  - ▶ Topology control is formed by channel assignment
  - ▶ Link capacity's formulation
  - ▶ In the thesis, interference is given.
    - ▶ Dynamical interference, or
    - ▶ Avoid the interference



## Related Works[6]

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- ▶ **[6] Centralized Channel Assignment and Routing Algorithms for Multi-Channel WMNs**
  - ▶ A. Raniwala, K. Gopalan and T.-C. Chiueh
  - ▶ Mobile Computing and Communications Review, Vol. 8, NO. 2
  - ▶ April, 2004
- ▶ In load awareness, the paper develops a set of centralized channel assignment, bandwidth allocation , and routing algorithms for multi-channel WMNs.

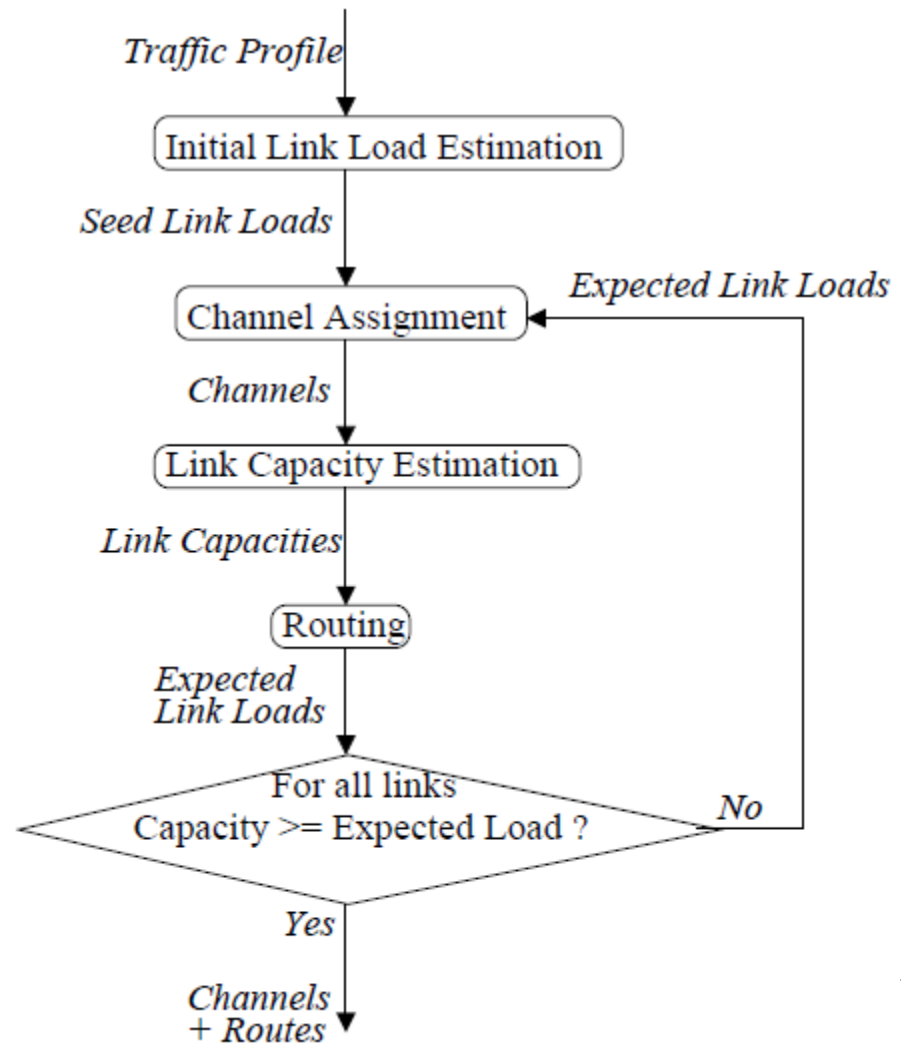
# Related Works[6]

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▶ A full multi-channel WMNs architecture requires:

- ▶ Topology Discovery
- ▶ Traffic Profiling
- ▶ Channel Assignment
- ▶ Routing

▶ Basic flowchart in the multi-channel MNWs.



# Related Works[6]

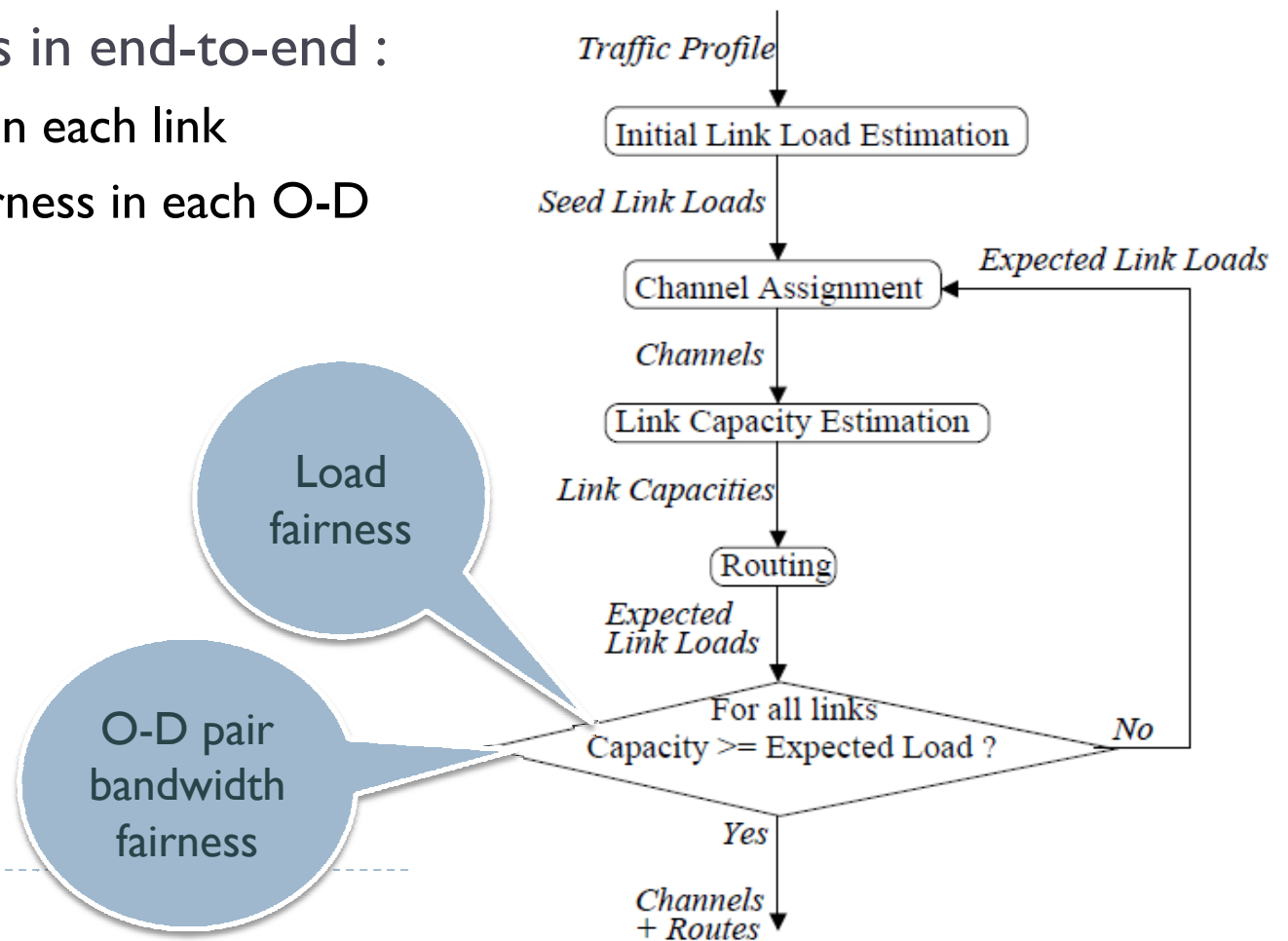
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## ▶ Contributions:

- ▶ 2 novel channel assignment and bandwidth allocation algorithms for the proposed multi-channel WMNs:
  - ▶ Neighbor Partitioning Scheme
  - ▶ Load-aware Channel Assignment
- ▶ The multi-channel architecture can accommodate occasional node failure/maintenance and joining.
- ▶ Assuming the traffic profile information can be obtained, then it can be used for modifying channel assignment and routing decisions on a periodic basis.

# Related Works[6]

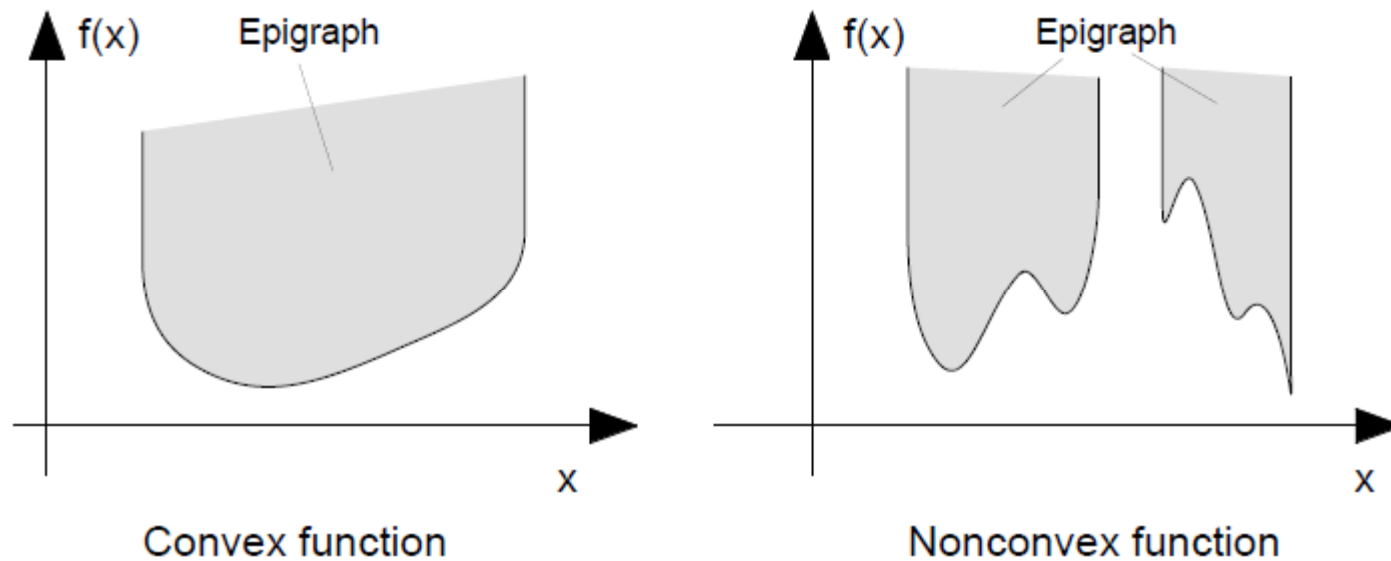
- ▶ What's in it for me?
  - ▶ A load-aware full multi-channel WMNs architecture
  - ▶ More concerns in end-to-end :
    - ▶ Load fairness in each link
    - ▶ Bandwidth fairness in each O-D pair



## Related Works[6]

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- ▶ However, Combining “Capacity Assignment problem” and “Routing problem” is a non-convex problem:



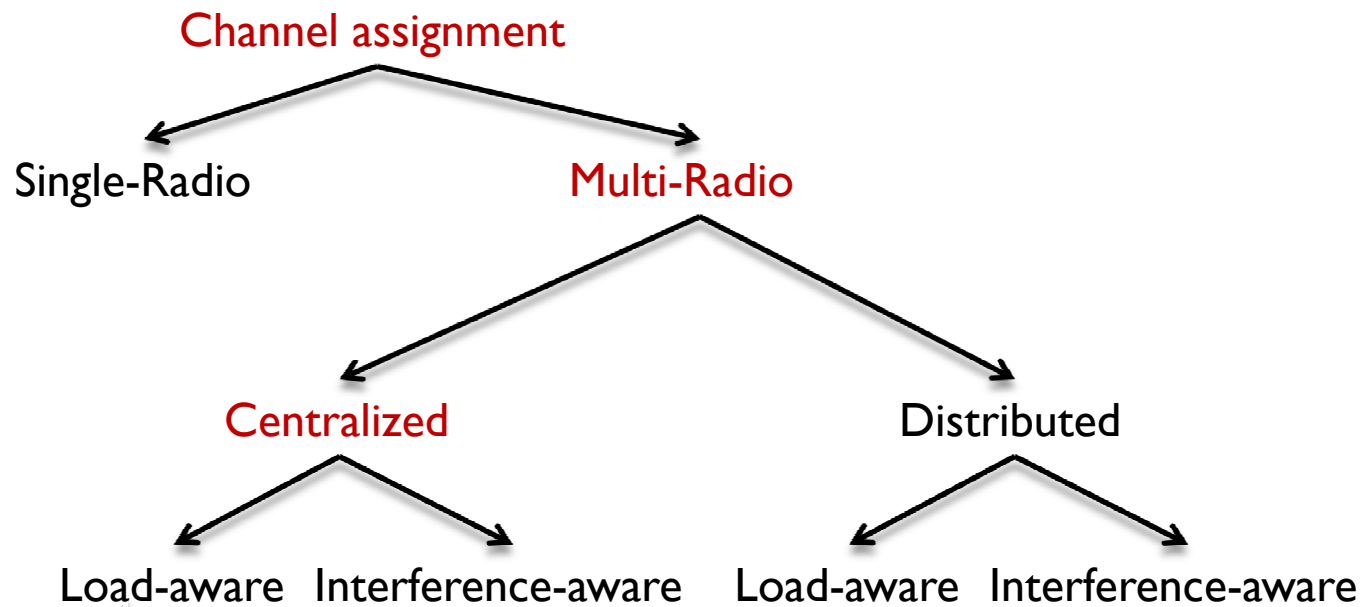
- ▶ Non-convex problem has multiple feasible regions
- ▶ multiple locally optimal points within each region

From MITOpenCourseWare (<http://www.myoops.org/twocw/mit/index.htm>)

# Problem Description

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## ► Problem taxonomy



Fairness or more QoS

# Problem Description

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- ▶ **Objective:**
  - ▶ Achieve both optimal channel assignment dynamically and load balancing fairly to increase performance in WMNs
- ▶ **Given:**
  - ▶ Number of radios in each node and Number of channels
- ▶ **More concerns:**
  - ▶ Traffic load fairness
  - ▶ Link capacity
  - ▶ Channel selection criteria
  - ▶ Time ( synchronization )
- ▶ **Assumptions:**
  - ▶ Unlimited buffer
  - ▶ Fixed Mesh routers

# Future Reading

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## ▶ Reading 1

- ▶ J. Tang, G. Xue and W. Zhang
- ▶ “Cross-Layer Design for End-to-End Throughput and Fairness Enhancement in Multi-Channel WMNs”
- ▶ IEEE transactions on Wireless Communications, Vol. 6, NO. 10, Oct. 2007.

## ▶ Reading 2

- ▶ A. H. M. Rad and V. W. S. Wong
- ▶ “Cross-Layer Fair Bandwidth Sharing for Multi-Channel WMNs”
- ▶ IEEE transactions on Wireless Communications, Vol. 7, NO. 9, Sep. 2008.



# Future Reading

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## ▶ Reading 3

- ▶ M. Kodialam and T. Nandagopal
- ▶ “Charactering the Capacity Region in Multi-Radio Multi-Channel Wireless Mesh Networks”
- ▶ International Conference on Mobile computing and networking, Aug. 2005.

**THANKS FOR YOUR LISTENING**