TriSAI 2011 Invited talk

A Cross-Layer Design for Cognitive Wireless Distributed Networks

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Outline

Goal

Improve Performance of Distributed Wireless Networks by Introducing New Ideas of "Cognitive" Path Control.

Outline

- Background
- Related Works and Problems
- Cross-Layer Cognitive Approach
- How to Control Local Path in Real Time
- Analysis and Simulation Results
- Conclusion

Focusing the Goal

Today's talk does Not focus on "Cognitive Radio",

But discusses,
Under constraint of a fixed amount of Spectrum and Power Resources,
How we can improve performance of Distributed Wireless Networks in terms of Transmission Reliability and Delay,
By developing a new Localized Path Optimization Method based on cross-layer technique.

Background

Distributed Wireless Communications

will play important roles in the future communications such as:

- Small power ubiquitous and sensor networks for realizing IoT (Internet of Things).
- Means for Cellular System Offloading to accommodate huge data traffic.
- Indoor coverage method by ad hoc Pico/Femto-cells.
- Easy-to-deploy Temporally Networks, after current network infrastructure suffered serious damage due to disasters.

However, many Distributed Wireless Communications require Multi-Hop Connection because of their limited power resource.

Issues of Multi Hop Communications

- Only one hop link error blocks whole transmission.

If a low quality link is initiated as a hop, multi-hop transmission will not succeed.

➡ Route determination is always critical.

Under fading environment, probability of link error changes after a route is determined.

➡ Should track fading channel.

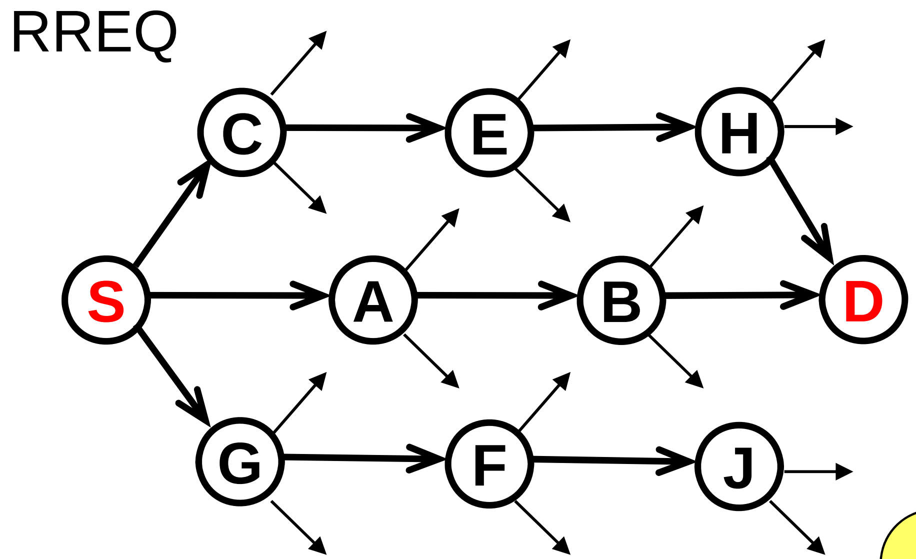
- If we add margin of each link by shortening link distance, it consumes much resource and increases multi-hop delay.

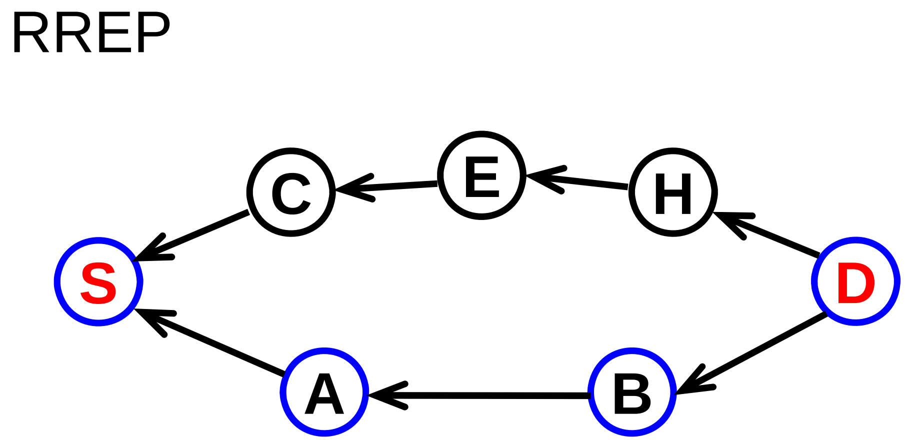
➡ High Reliability and small Delay/Resource conflict.

Multi Hop Route Determination Method

- On-Demand Routing Protocol such as AODV

  determines multi-hop route by exchanging Route Request (RREQ) and Route Reply (RREP) messages.



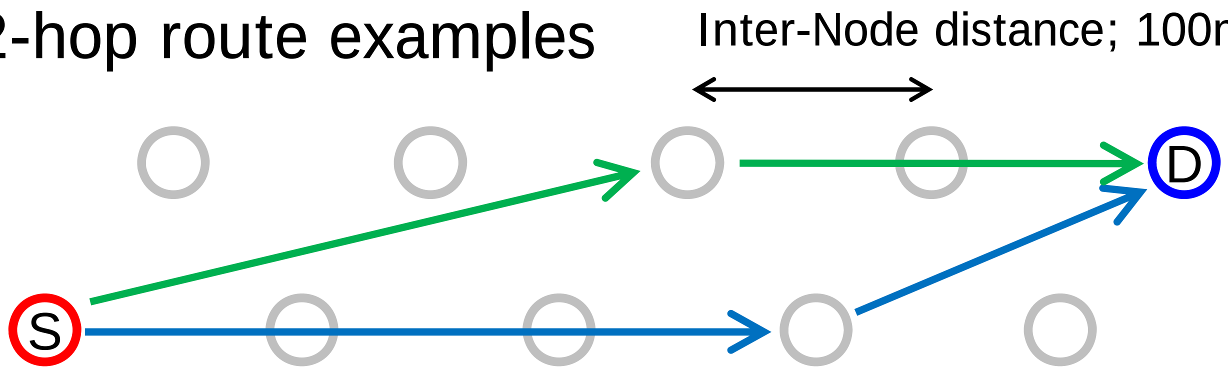


Sender node S chooses the minimum hop counts route (S-A-B-D).
Thus, Hop links have longer distances and little tolerance for fading.

Simulated Multi Hop Routes with AODV

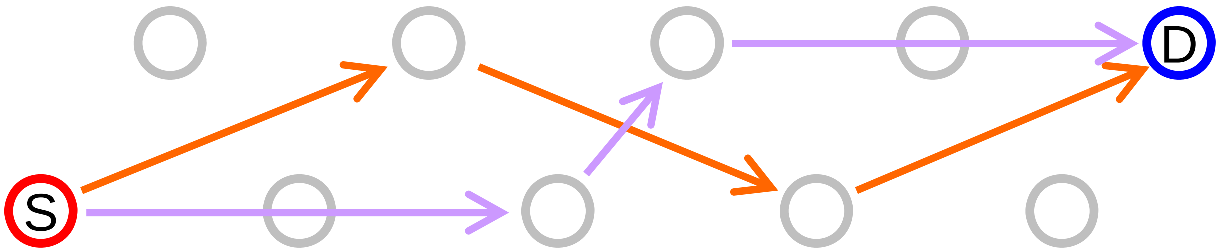
[Simulation Condition] IEEE802.11b, Rayleigh fading, No ARQ

- 2-hop route examples



2-hop routes
Generation Prob. 4%
Delivery Success 2%
Delay 2 hops

- 3-hop route examples

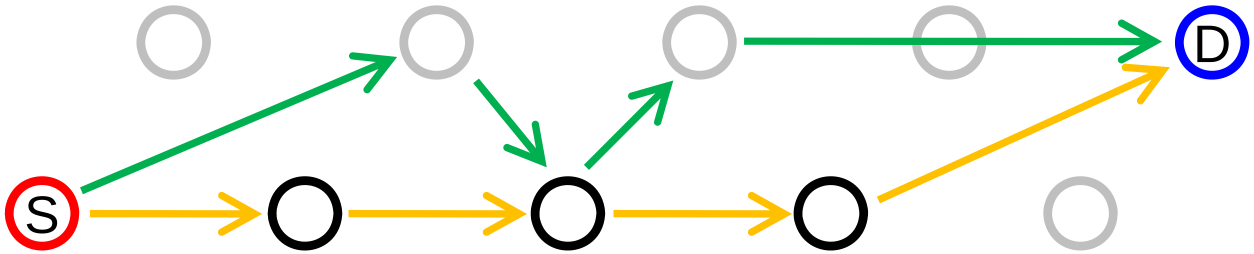


3-hop routes
Generation Prob. 77%
Delivery Success 23%
Delay 3 hops

2 and 3 hop routes include long-distance links.
Multi-hop delay is small, packet delivery ratio is poor.

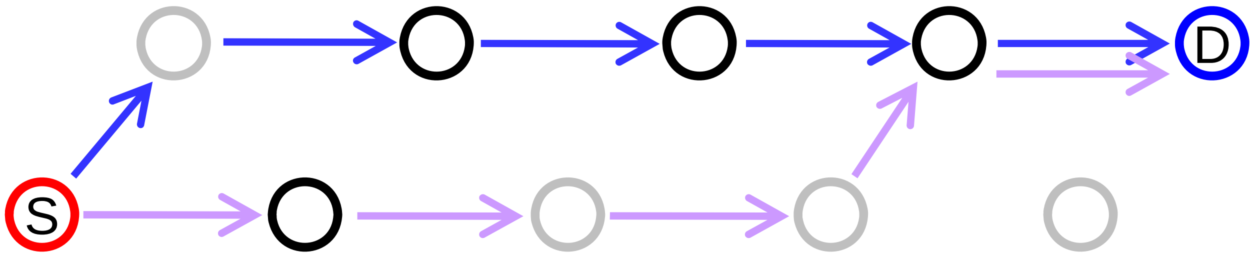
Simulated Multi Hop Routes with AODV

- 4-hop route examples



4-hop route
Generation Prob. 17%
Delivery Success 41%
Delay 4 hops

- 5-hop route examples



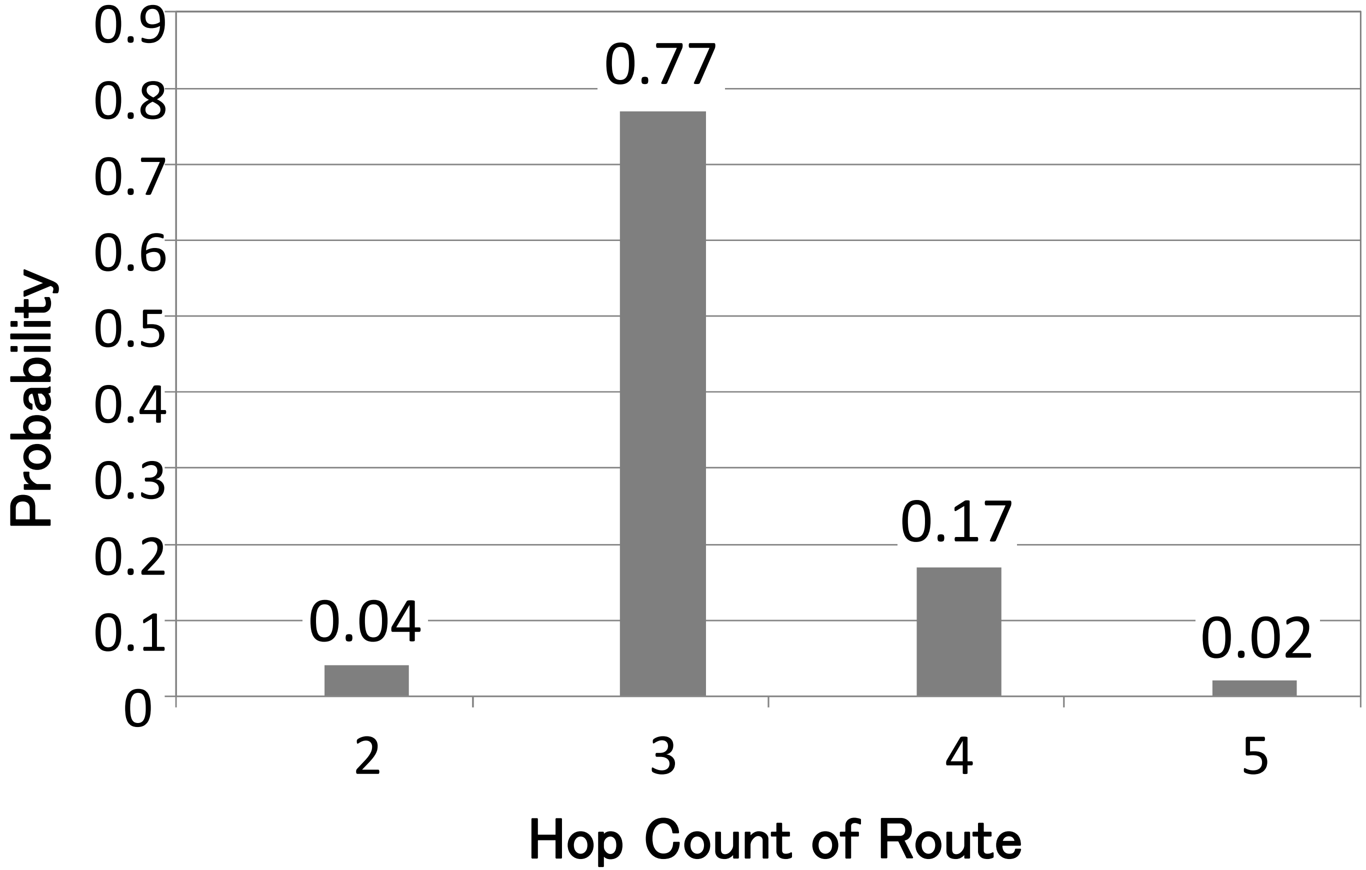
5-hop route
Generation Prob. 2%
Delivery Success 52%
Delay 5 hops

4 and 5 hop routes consist of shorter links.
Packet delivery ratio is better, multi-hop delay is large.

Statistic of Routes Determined by AODV

Hop Count	Number of generation	Node #s on the route						Hop distance (x100m)					Route distance (x100m)	Delivery Ratio
2	1	1	5	10				2	2.65				4.65	0.03877198
	2	1	6	10				2.65	2				4.65	0.03877198
	1	1	4	10				1.73	3				4.73	0.01139303
3	4	1	3	6	10			1	1.73	2			4.73	0.26933729
	16	1	3	7	10			1	2	1.73			4.73	0.26933729
	22	1	5	7	10			2	1	1.73			4.73	0.26933729
	3	1	5	8	10			2	1.73	1			4.73	0.26933729
	4	1	2	6	10			1	2	2			5	0.19067483
	1	1	7	9	10			3	1	1			5	0.01609003
	24	1	4	7	10			1.73	1.73	1.73			5.19	0.25492295
	3	1	4	5	10			1.73	1	2.65			5.38	0.05182604
4	1	1	3	5	7	10		1	1	1	1.73		4.73	0.53730042
	1	1	3	7	8	10		1	2	1	1		5	0.38037685
	1	1	3	4	6	10		1	1	1	2		5	0.38037685
	2	1	3	4	8	10		1	1	2	1		5	0.38037685
	1	1	5	7	9	10		2	1	1	1		5	0.38037685
	1	1	2	4	7	10		1	1	1.73	1.73		5.46	0.36001993
	1	1	2	5	7	10		1	1.73	1	1.73		5.46	0.36001993
	2	1	3	4	7	10		1	1	1.73	1.73		5.46	0.36001993
	2	1	4	5	7	10		1.73	1	1	1.73		5.46	0.36001993
	1	1	4	6	7	10		1.73	1	1	1.73		5.46	0.36001993
	1	1	4	6	9	10		1.73	1	1.73	1		5.46	0.36001993
	2	1	4	7	9	10		1.73	1.73	1	1		5.46	0.36001993
	1	1	2	7	9	10		1	2.65	1	1		5.65	0.07319235
5	1	1	3	4	5	8	10	1	1	1	1.73	1	5.73	0.50844518
	1	1	3	4	8	9	10	1	1	2	1	1	6	0.35994905

Hop Count Distribution by AODV



Majority is the 3 hops.
However, 19 % are 4 or 5 hops,
4% are 2 hops.

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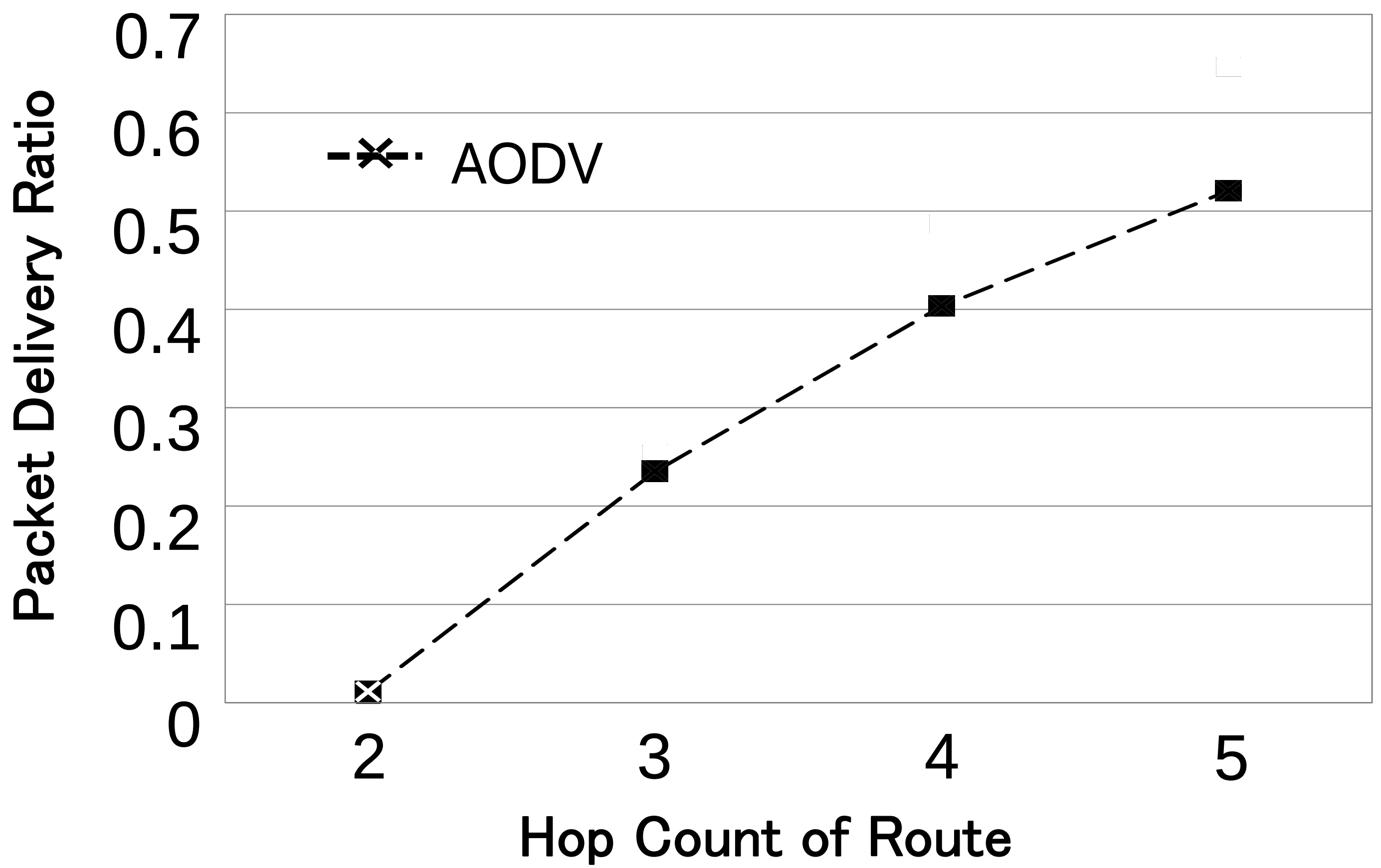
Packet Delivery Ratio vs. Hop Count of Route



Routes with large hop count have better packet delivery ratio, although the ratio is still not good. To the contrary, multi-hop delay increases.

➡ Suggest great influence of routing

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Current Multi Hop Technology

- MANET Routing Protocols cannot track link quality fluctuation due to fading.

- MAC-ARQ is not effective to cover link error in slow fading conditions, i.e. nodes are fixed or not moving fast.

  If we set longer ARQ retransmission duration, it can cover link error caused by slower fading.
  However, it will reduce link throughput and increase delay.

- End-to End ARQ (TCP-ARQ) consumes much network resources. Therefore it is not efficient for covering single hop error.

Previous Approaches for Improvement

- A lot of methods in different approaches have been studied to improve reliability of multi-hop wireless communication.

NW Layer Multipath Routing

- Route redundancy improves reliability
- Consumes much network resources such as power and spectrum.
- Cannot adapt to fast fading.
- Thus, not cost-effective in wireless environments.

PHY Layer Cooperative Diversity

- Reliability improvement is large with reasonable spectrum efficiency.
- Receiver signal processing is heavy for small power source devices.
- Relay node determination is not coordinated with multi hop routing.

These approaches are within the framework of the OSI layer.

Current OSI Layer Framework

NW Layer

- End-to-End Connection Management (TCP, IP Addressing)
- End-to-End Routing (AODV, DSR etc.)

MAC Layer

- Link Management (MAC-ARQ, MAC Addressing)
- Multiple Access Management (CSMA/CA, RTS/CTS)

PHY Layer

- Modulation/Demodulation, Encoding/Decoding
- Channel Measurement/Channel Quality Management

From View Point of Technical Strategy

- Current multi-hop techniques are based on the OSI layer model.
- OSI layer model defines the roles of each layer, which makes engineers easy to develop whole system by work sharing.
- However, it does not mean the system performance can be maximized by the layer model.
- On the contrary, “walls” between layers often limit the potential of the system.

Then, what shall we do?

We should get over the walls by acquiring multi-layer knowledge and create new composite-style techniques.

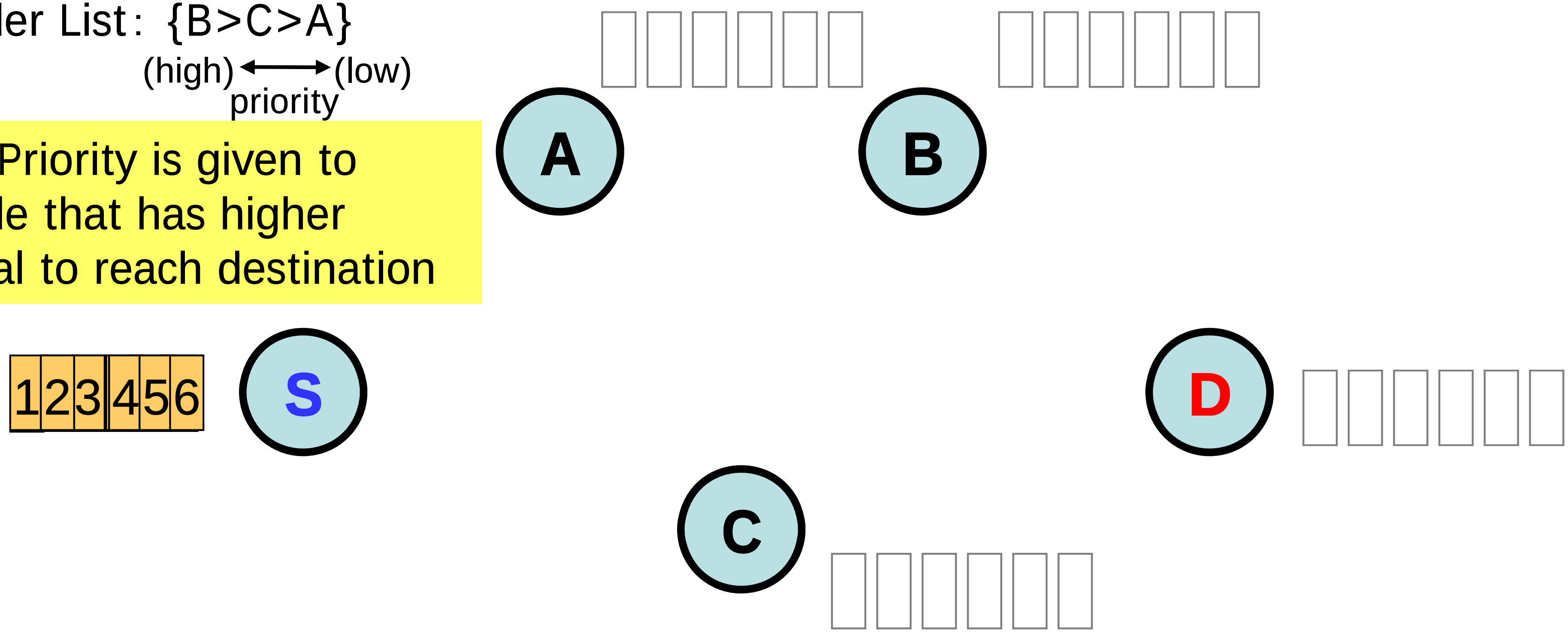
Example of Cross-Layer Routing Protocol

- Extremely Opportunistic Routing (EX-OR) by S. Biswas (2004)

Forwarder List： {B>C>A}

(high) ⟷ (low)
priority

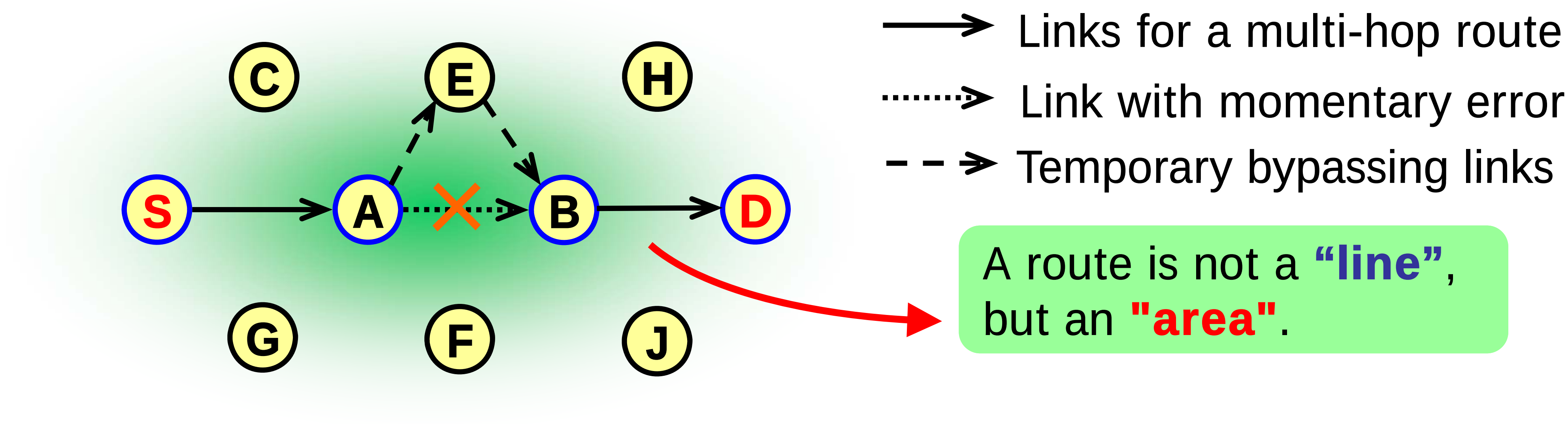
Higher Priority is given to the node that has higher potential to reach destination



- EX-OR gains route diversity effect without network resource increase. Effectiveness was proved in roof-top mesh network experiments.
- However, it is difficult to apply this method to networks with rapid channel changing , because it needs to calculate profit function for each link from averaged link quality.

Utilizing Available Paths in Local Area

- Reliability of a multi hop route can be improved by selecting an “available path” in local area when transmitting a packet.



A route is not a **“line”**, but an **"area"**.

Distributed Path Control by Environment-Adaptive (Cognitive) Behavior of individual nodes.
It is possible by creating a new cross-layer multi-hop protocol.

Then, How shall we do?

Cross-Layer Approach Lead by MAC

- Only MAC Layer can interwork with both PHY and NW Layers.

NW Layer
Route Determination,
End-to-End Transmission Quality Measurement

Route Information

MAC Layer → Fast Route Management is possible

Link Quality/Error

PHY Layer
Individual Link Quality Measurement (RSSI, CRC)
Link Quality Adaptations (AMC)

- However, the role of current MAC layer is limited to manage single link, not covers multi-hop links.

Enhancement of MAC protocol to multi hop links is necessary.

Basic Concept of Proposal

Cross-layer Cognitive Path Control method lead by MAC

NW Layer determines a basic route

- On-demand Routing Protocols such as AODV can be used.
- Repair route after a node has moved out from the route.

Enhanced MAC Layer selects an "available local path" after transmitting a packet

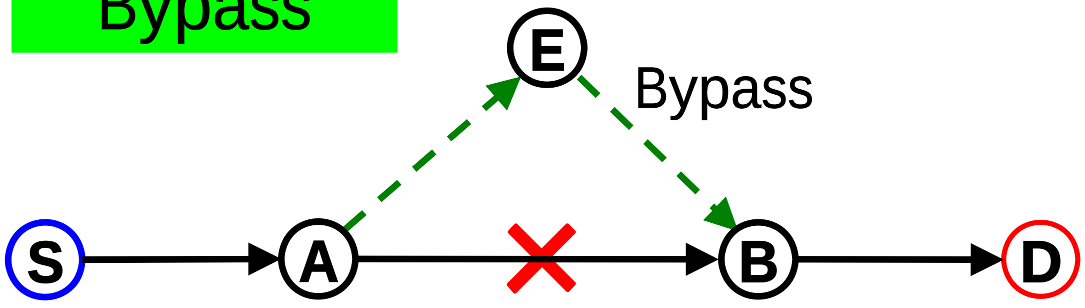
- "Available local paths" are;
  the default path, bypassed path, and shortcut path
- Nodes on the default route and in its vicinity prepare for Bypass and Shortcut, by referring route information they have.

Dynamic Bypass and Shortcut

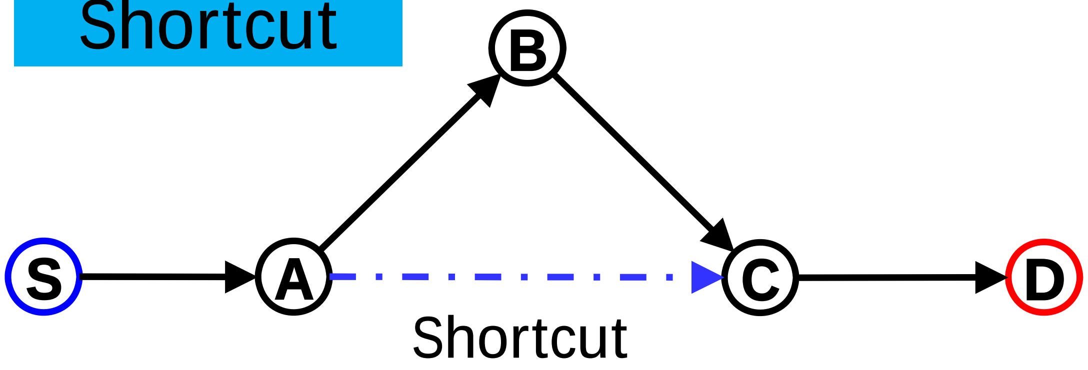
Due to **Fading, and Interference**

- Sometimes Does not Reach → Temporary Bypass
- Sometimes Over Reach → Temporary Shortcut

Bypass



Shortcut



→ Basic Route

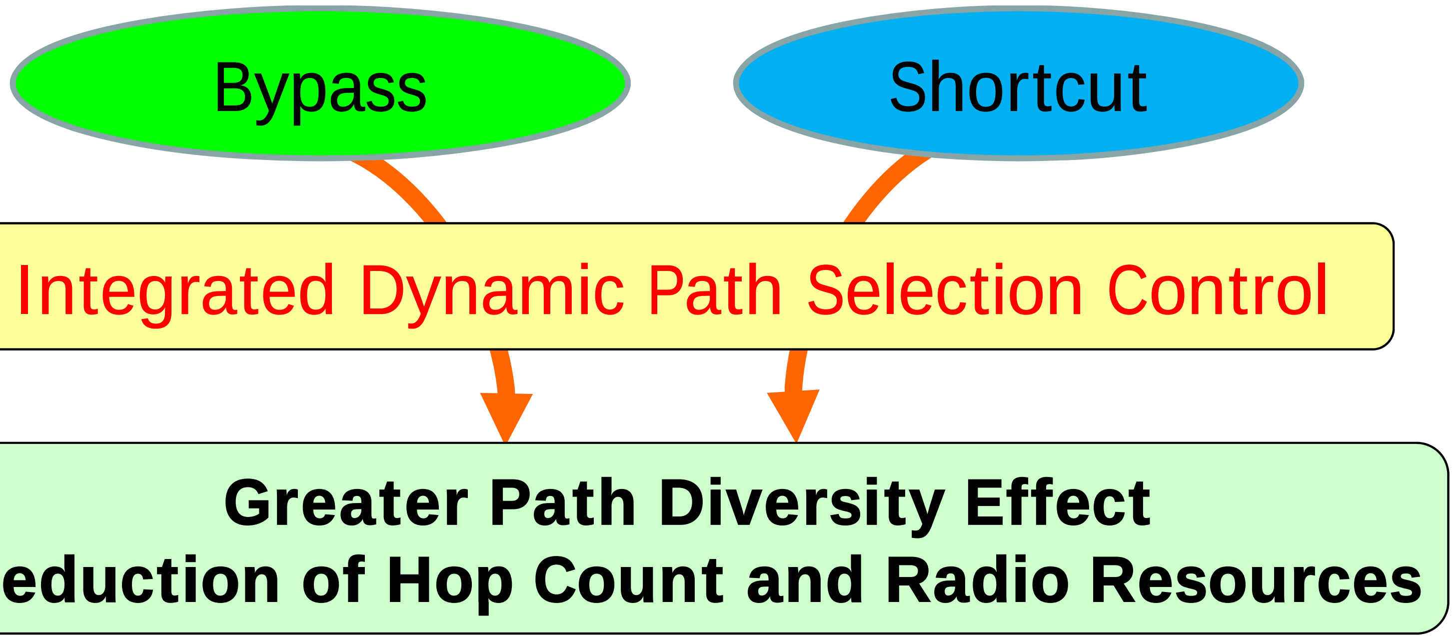
Basic Routes were determined at the time of Route Search. However, Link Quality changes due to fading. Thus the Basic Route is not always the best one.

Multi hop Route should be dynamically changed according to the status of each Link

Integration of Bypass and Shortcut

Bypass	; Path Diversity Effect
Shortcut	; Reduction of Hop Count and Radio Resources, Path Diversity Effect

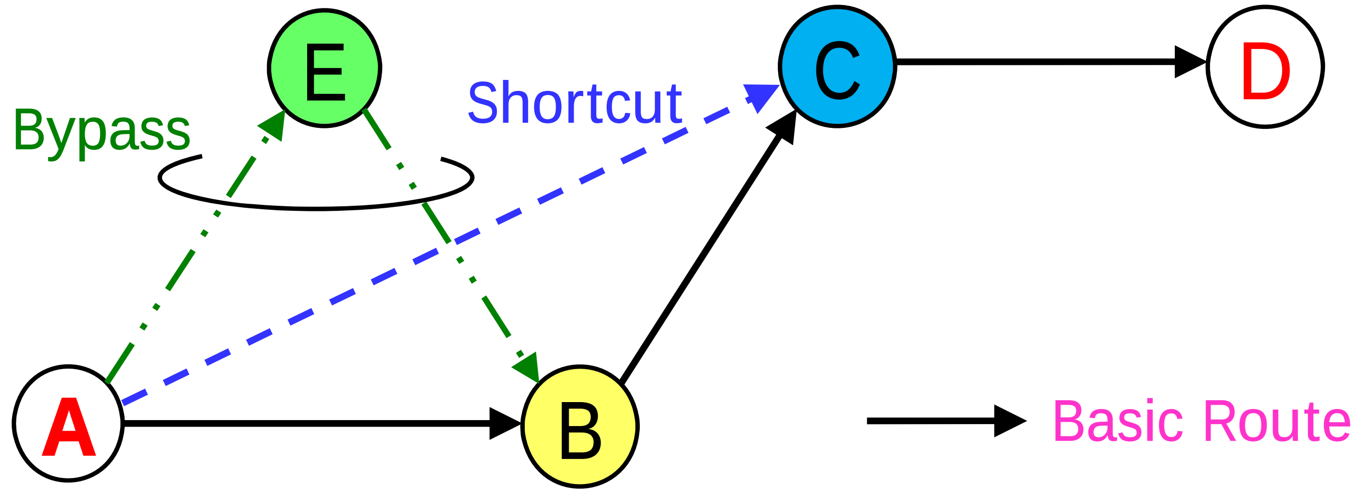
- Integration of two Methods will gain Greater Effects



Integrated Dynamic Multi-Hopping (IDMH)

- Issue; Conflict happens among Candidate Paths.

  Ex；Transmitted Signal from node A is captured by
  node C（shortcut）, B（Basic route）, E（Bypass）.
  They try to forward it to the next hop nodes.



- Integrated Dynamic Path Selection Control should
  - ✓ be localized,
  - ✓ avoid any conflict among candidate paths, and
  - ✓ choose the best path.

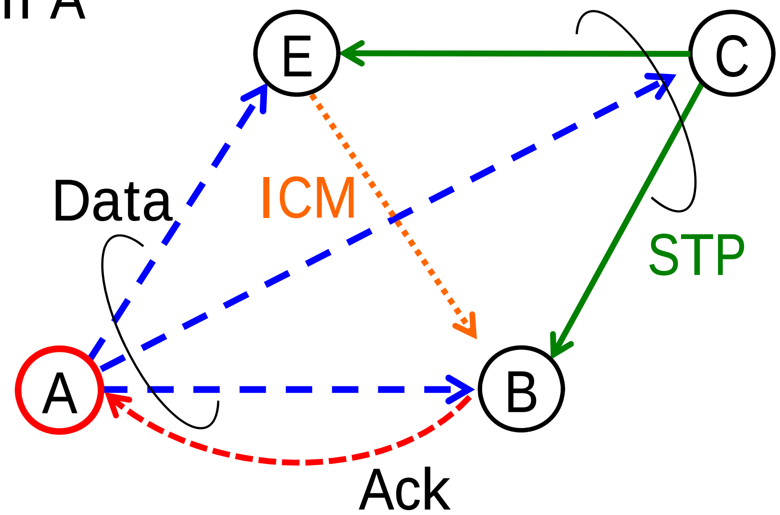
Priority of Paths and Cognitive Control Actions

1. Shortcut（A→C）
2. Default Path（A→B→C）
3. Bypass（A→E→B→C, A→B→E→C）

1. Priority is given to the paths with smaller hop count.
2. Avoid Contention among Paths and Stop Unnecessary Packet Transmission.

Table. 1 Cognitive Action after Transmission from A

	Packet reception status			Next action		
	A-C	A-B	A-E	node C	node B	node E
Case I	Success	-	-	Send STP and Forward the packet to D	-	-
Case II	Fail	Success	-	-	Send Ack and Forward the packet to C	-
Case III	Fail	Fail	Success	-	-	Send ICM and Bypass the packet to B



CSMA/CA based Control Messages are introduced

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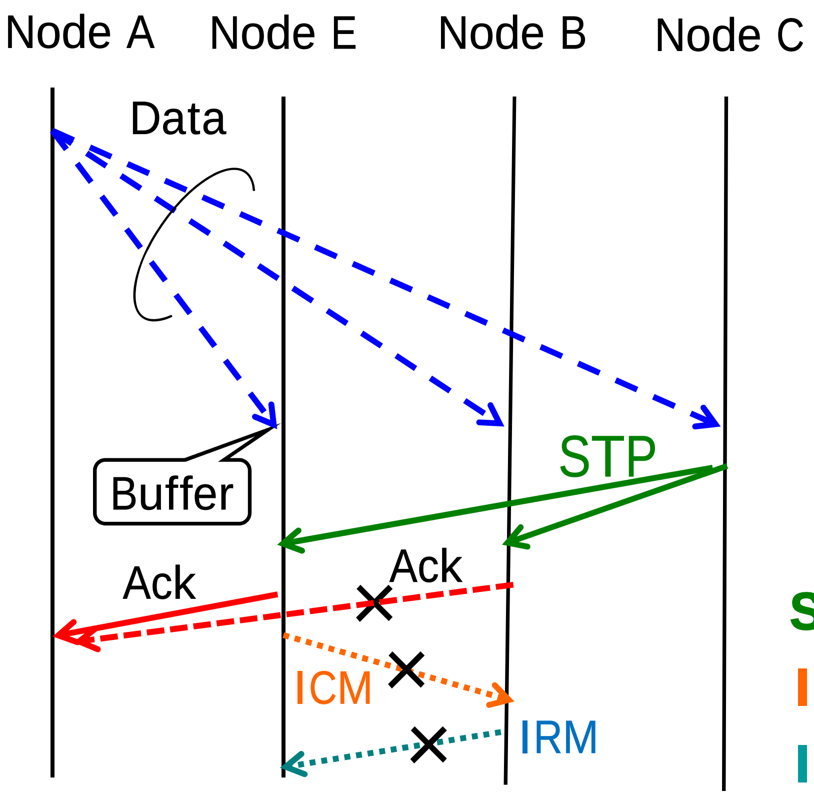
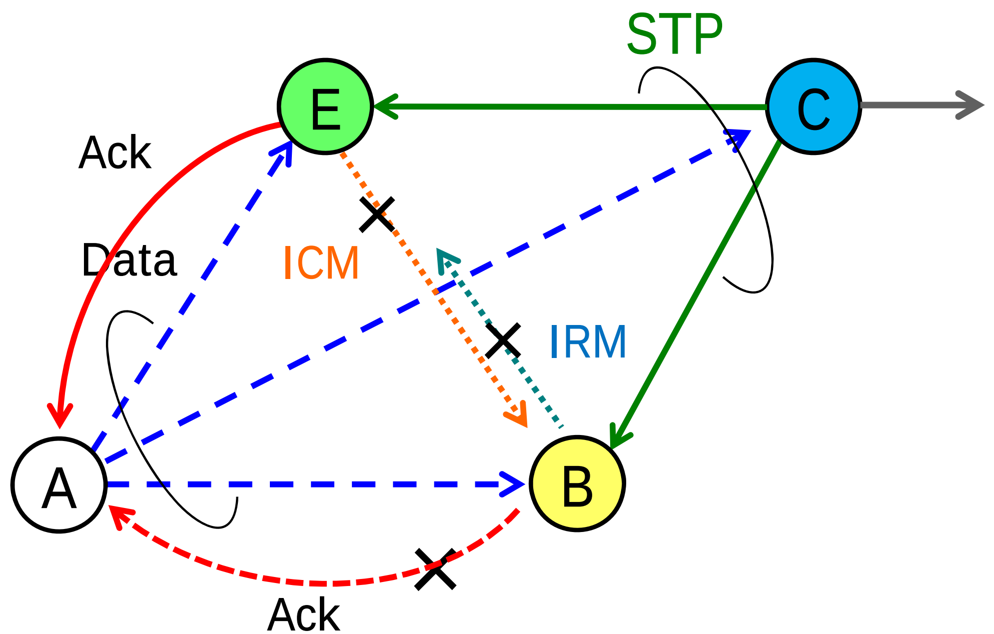
Control Messages and Control Sequence

- Case Ⅰ, Nodes B, C, E can receive data packet from node A





STP: Stop Forwarding Message (Including Ack**)**

ICM: Intermediary Candidate Message

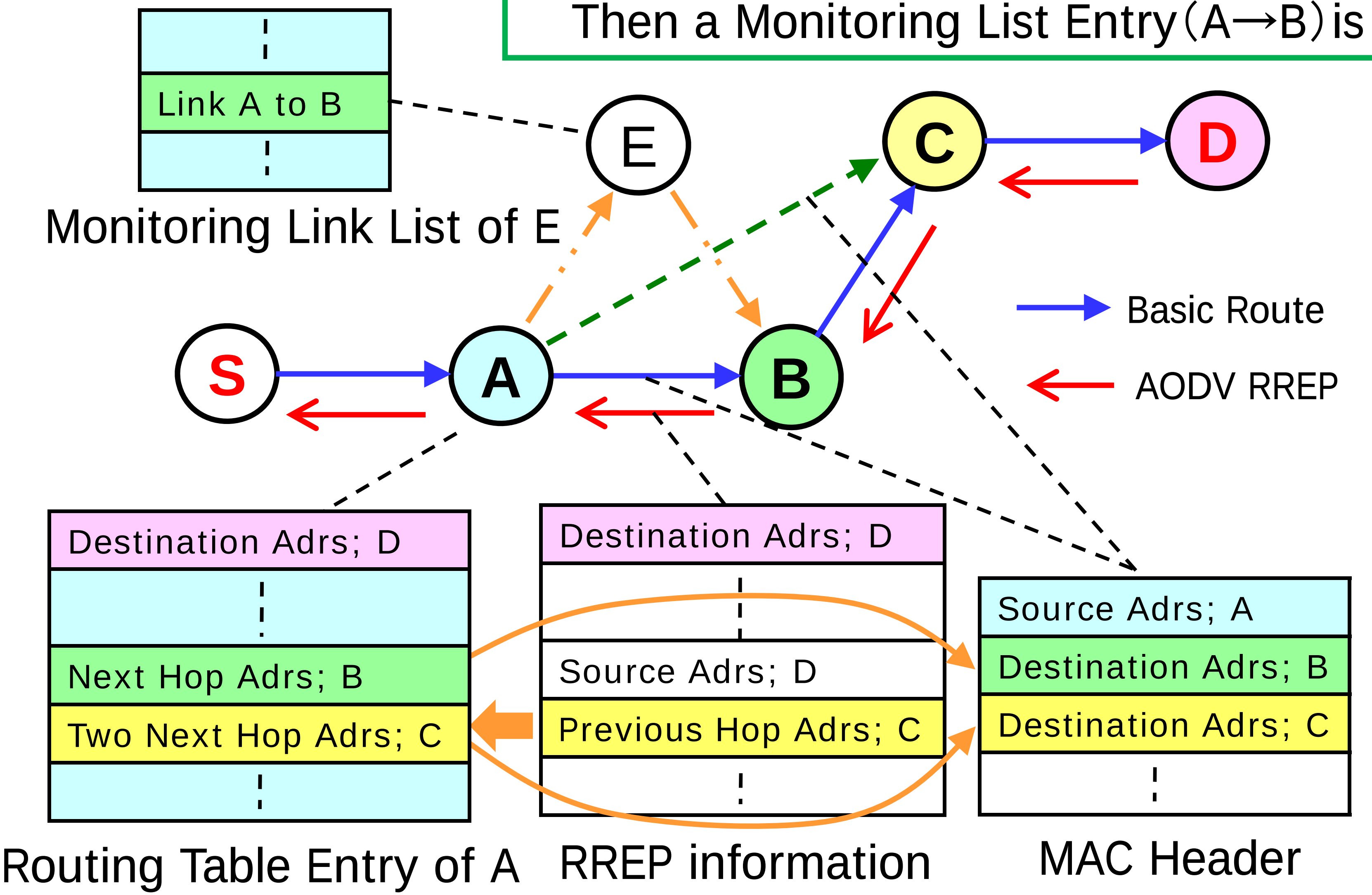
IRM: Intermediary Request Message

In order to give priority, IFS (Inter Frame Spacing) of CSMA/CA for three control messages are differentiated as

IFS(STP) < IFS(Ack) < IFS(ICM)

Mod. of Routing Table, RREP, MAC Header

Bypass; RREP from B is monitored by node E.
Then a Monitoring List Entry (A→B) is created.



Shortcut; Adding Previous Hop Address (C) to RREP information,
Routing Table Entry of A, and MAC Header sending by A.

Transmission Probability of Paths for IDMH

- **One Hop Path (Shortcut)**

$$P_{1h} = P_{pathI} = P_{AC} = P_1$$

- **Two Hop Path (Basic Route)**

$$P_{2h} = (1 - P_{1h}) \cdot P_{pathII} = (1 - P_{1h}) \cdot P_0^{\ 2}$$

- **Three Hop Paths (one Bypass)**

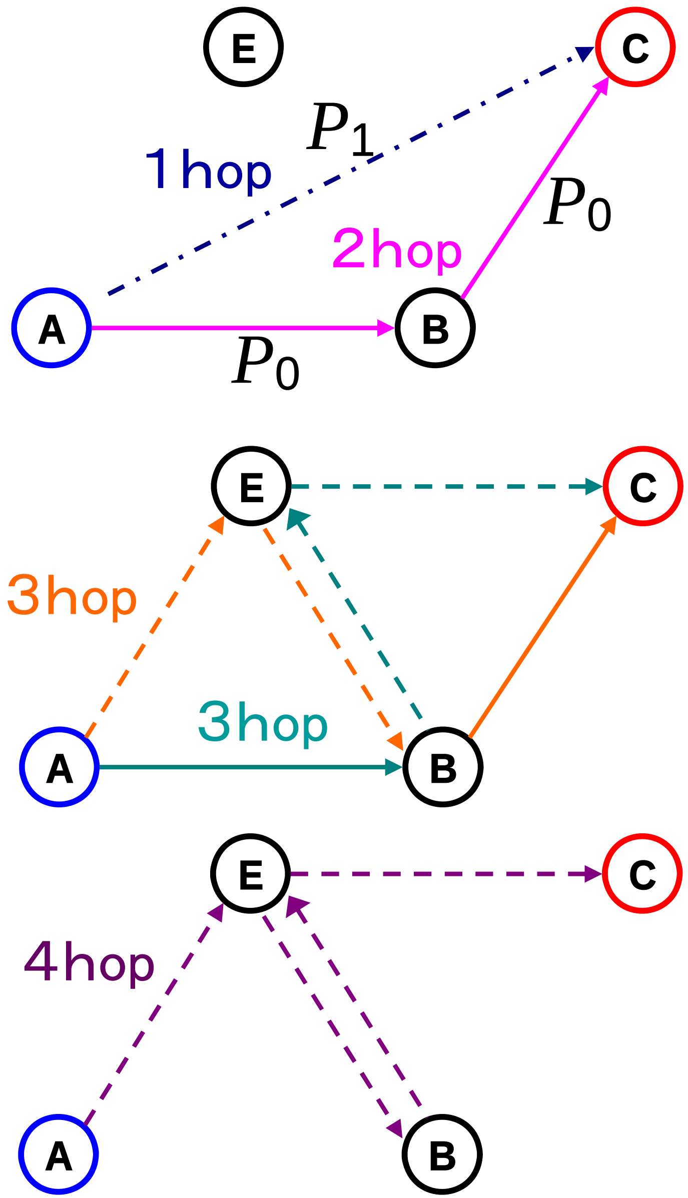
$$P_{3h} = (1 - P_{1h}) \cdot (1 - P_{2h}) \cdot P_{pathIII}$$

$$= 2 \cdot (1 - P_{1h}) \cdot (1 - P_{2h}) \cdot P_0^{\ 4} \cdot P_0$$

- **Four Hop Path (Two Bypass)**

$$P_{4h} = (1 - P_{1h}) \cdot (1 - P_{2h})^2 \cdot P_{pathIV}$$

$$= (1 - P_{1h}) \cdot (1 - P_{2h})^2 \cdot (P_0^{\ 4})^2$$



Average Hop Count for Successful Transmissions

- Packet Transmission Success Probability; P_I
- p-Hop Path（p=1,2,3,4）Selection Probability; K_p
- Average Hop Count for Successful Transmissions; E_h

$$E_h = \frac{\sum_{p=1}^{4} K_p \cdot p}{P_I}$$

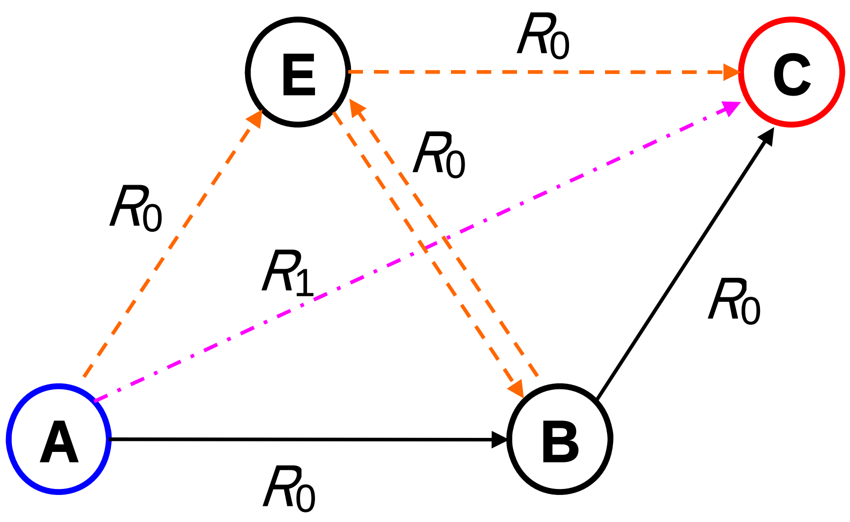
$$\begin{cases} K_1 = P_{pathI} = P_{AC} \qquad K_2 = (1-P_{pathI})P_{pathII} = (1-P_{AC})P_{AB} \cdot P_{BC} \\ K_3 = (1-K_1-K_2)(P_{pathIIIa} + P_{pathIIIb} - P_{pathIIIa} \cdot P_{pathIIIb}) \\ K_4 = (1-K_1-K_2-K_3)P_{AE} \cdot P_{BE}^{\;2} \cdot P_{CE} \end{cases}$$

Evaluation Condition

RF Channel Conditions

RF Frequency	2.4 GHz
Bit rate	11 Mbps
Tx Power	15 dBm
Rx Sensitivity	-81 dBm
Path Loss Model	ITU-R p.1411
Antenna Heights	1.5 m
Fading	Flat Rayleigh

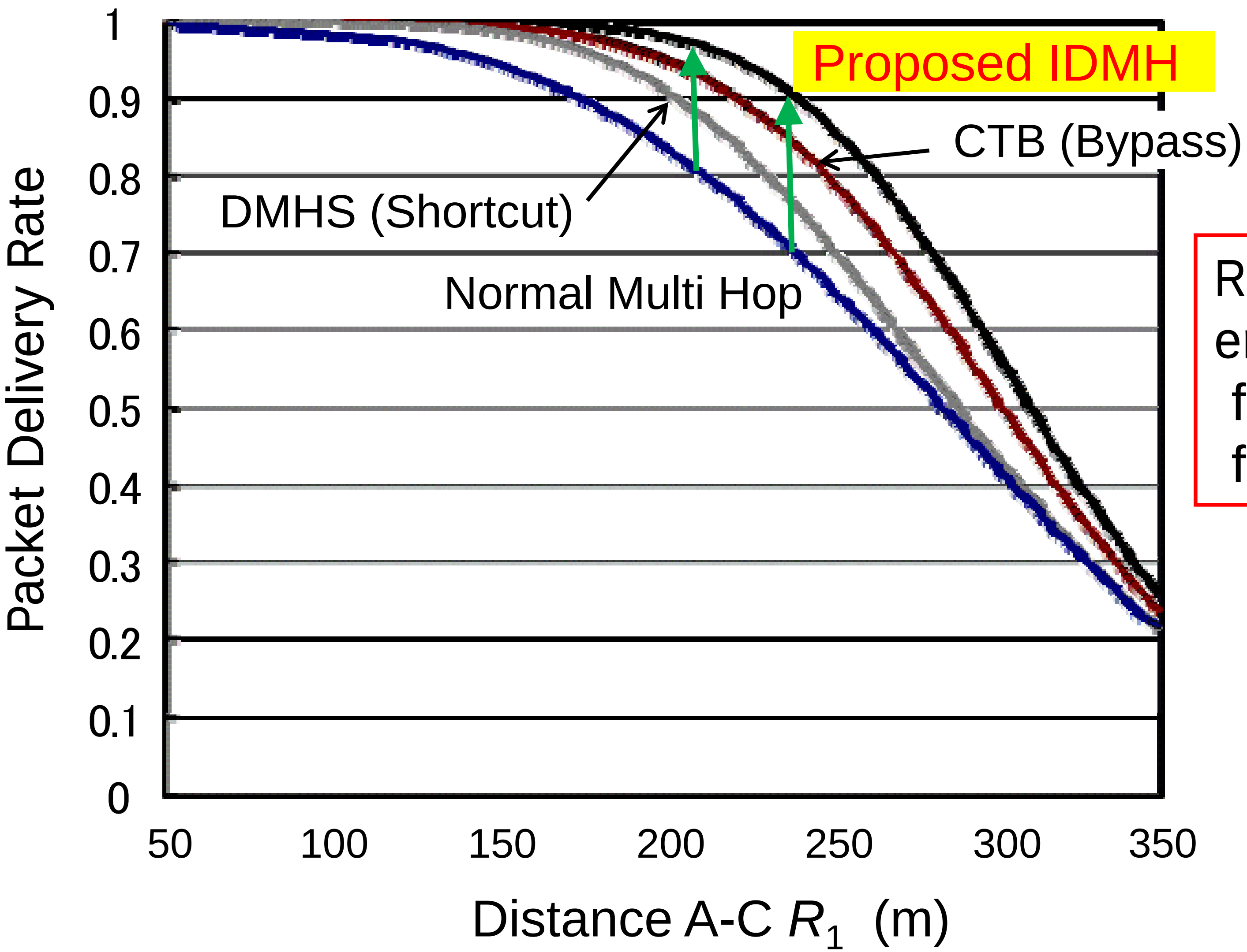
Location of Nodes



Nodes are located on a regular triangle lattice with the distance of R_0 to the adjacent nodes.

$$R_1 = \sqrt{3} R_0$$

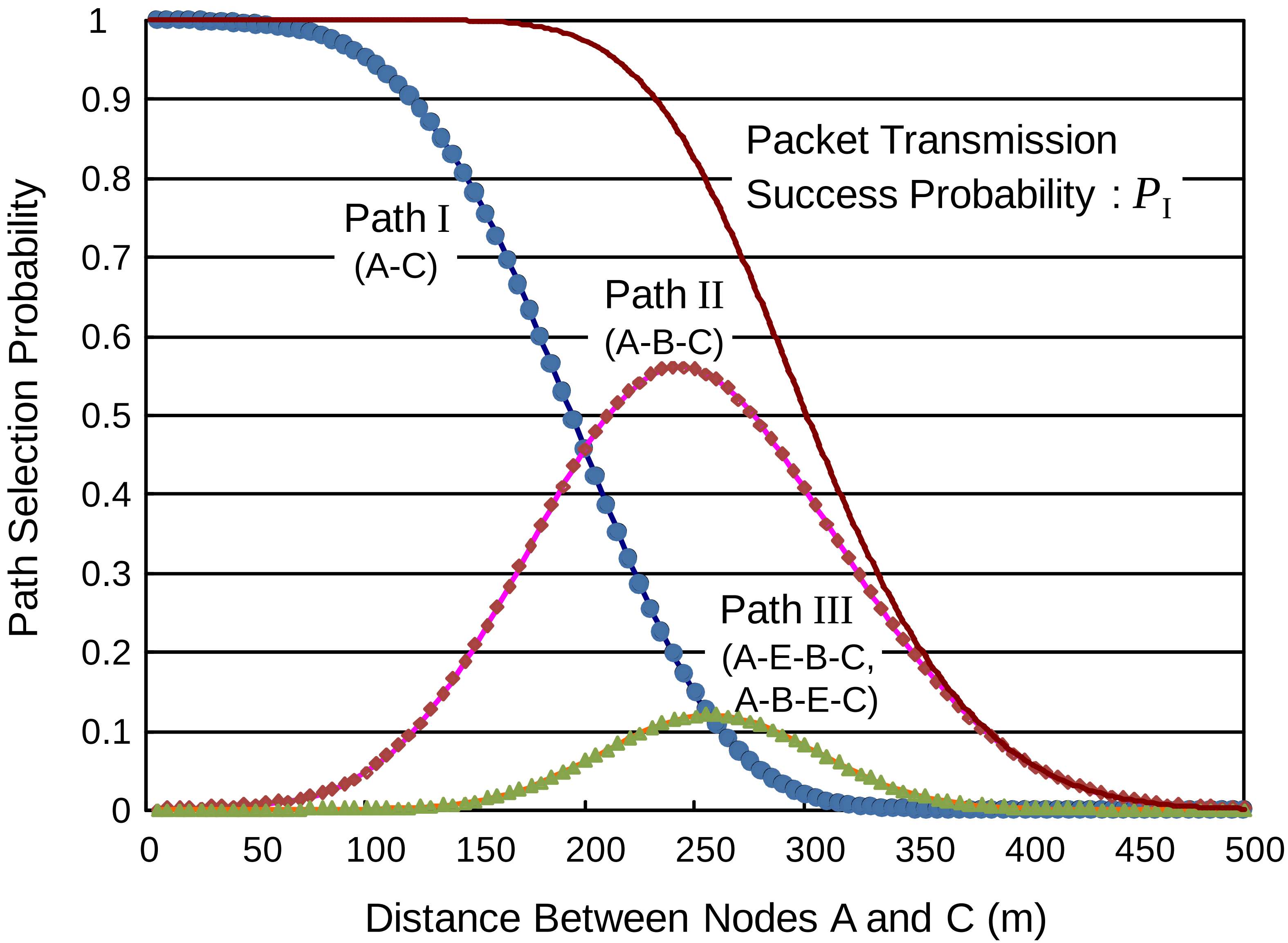
Packet Transmission Success Probabilities



Reduce packet error
from 20% to 3%
from 30% to 9%

The IDMH has the best packet success probability, because it can choose one of three candidate paths.

Path Selection Probabilities for IDMH



The IDMH MAC provides automatic migration among Shortcut, Normal 2-Hop, and Bypassed paths.

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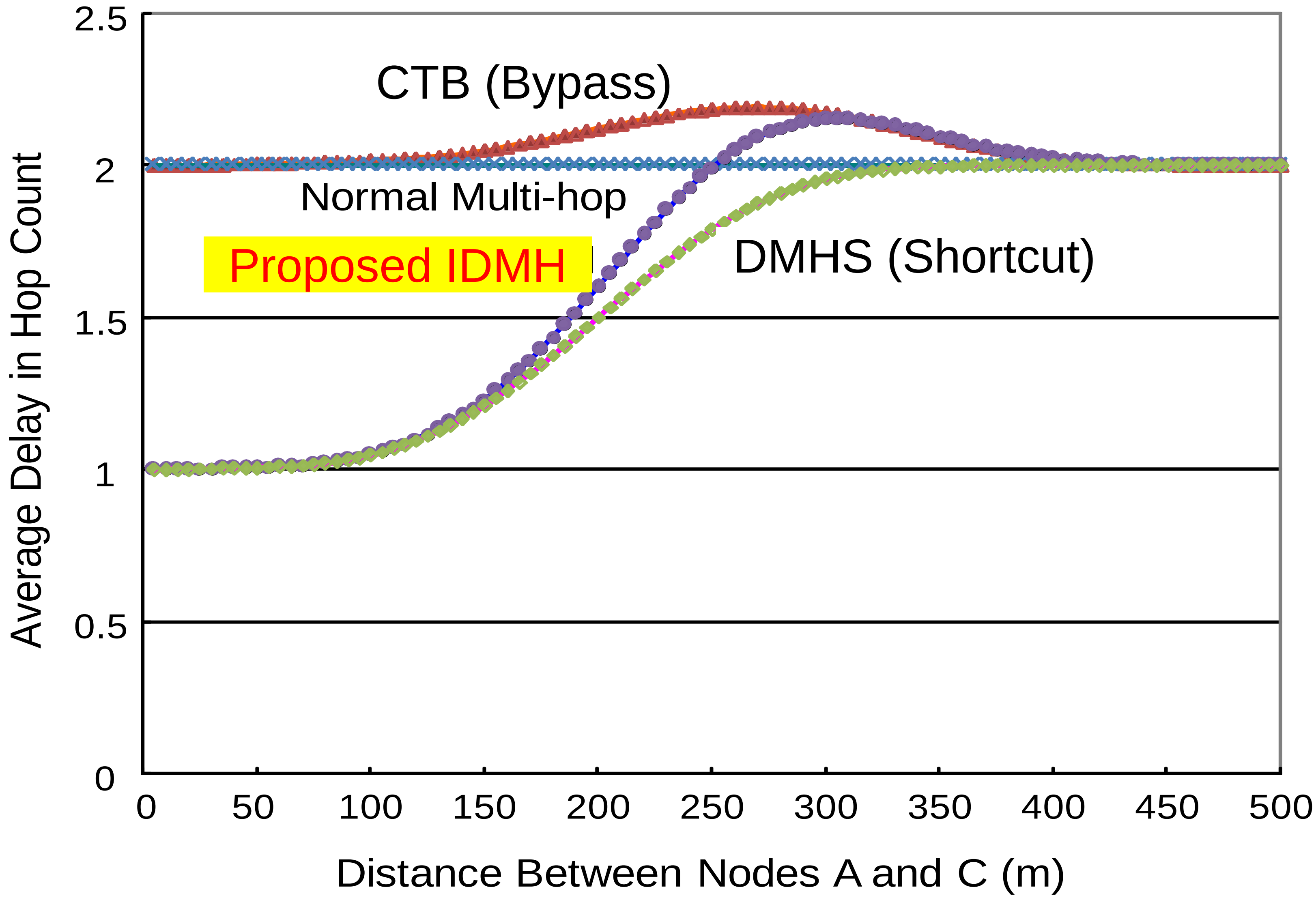
Average Transmission Delay in Hop Count



The IDMH can reduce the multi-hop delay when node distance is less than 250 m.

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Conclusions

- The Integrated Dynamic Multi-Hopping (IDMH) scheme employing cross-layer and Cognitive approach has been proposed

  - to provide better packet transmission probability gained from three-path diversity effect

  - to reduce multi-hop delay and save radio resources by giving priority to shorter hop paths

- The gained improvements promise increase of throughput in multi-hop networks.

  It will be confirmed by the ongoing work.

References for Our Works

1) Y. Yamao and K. Nagao, “Cognitive Temporary Bypassing for Reliable Transmission in Wireless Ad Hoc Networks,” Proc. IEEE ISWCS2007, Trondheim, Oct. 2007.

2) K. Nagao and Y. Yamao, “Cognitive Temporary Bypassing for Reliable Multi-Hop Transmission in Wireless Ad Hoc Networks,” IEICE Trans. Commun., Vol. E93-B, No.12, pp.3391-3399, Dec. 2010.

3) Y. Yamao, Y. Kadowaki and K. Nagao, “Dynamic Multi-Hopping for Efficient and Reliable Transmission in Wireless Ad Hoc Networks,” Proc. APCC2008, 16-PM-D-2-4, Tokyo, Oct.2008.

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5) Y. Yamao, Y. Kida and Y. Kadowaki, " Cross-Layer Multi-Hopping Scheme for Efficient and Reliable Transmission in Fading Environment," Proc. IEEE VTC2010-Fall, Ottawa, Sept. 2010.

Thank you for listening!