A Flexible Retransmission Policy For Industrial Wireless Sensor Actuator Networks

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Introduction

Wireless sensor actuator networks (WSANs) are attractive solution to industries

Most of the WSANs are based on WirelessHART and ISA100.11a

A challenge is to maintain reliability and real-time properties

WirelessHART use link-centric policy (LCP) schedule

Introduction

LCP doesn't adapt to the link quality and retransmission provision can be wasted

This paper try to improve the situation by using a flow-centric policy (FCP)

They contribute by:

- proposing a FCP
- developing a unified scheduling framework for LCP and FCP
- developing a method to configure the number of retransmissions

Current situation

Predictability or flexibility, CSMA/CA and TDMA

- The industries use TDMA for the predictability

Transient link failures

- Addressed by a fixed number of retransmission
- Little work on the choice of this number

System Models

The communication primitive is a real-time flow

A flow i has:

- A period Pi
- A Deadline Di
- A path Πi
- A phase ϕi
- Some end-to-end reliability requirement
- A fixed priority

We suppose Di < Pi

System Models

A centralized scheduler determines the slot and channel for each transmission

A schedule is feasible if:

- Each node transmits or receives only once in a time slot and on a single channel
- Hop-by-hop forwarding constraints are maintained such that senders receive packets before forwarding them
- No more than one flow transmits or receives on each channel in a time slot
- Each flow instance meets its respective deadline and reliability constraints

Design

How FCP and LCP are constructed and comparison between them

Single Real-time flow

Planning and Runtime Adaptation

Configuring Retransmissions

Empirical Results for Single Flows

Multiple Real-time flows

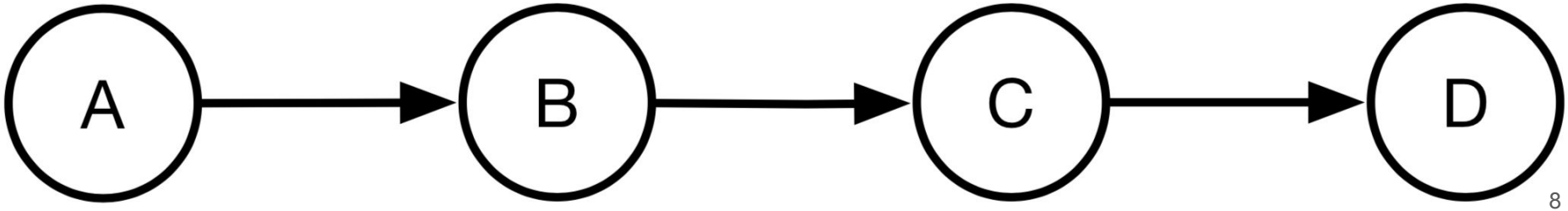
Design: Planning

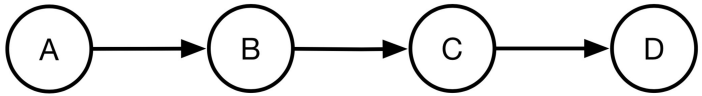
An offline planner constructs plans that are used to execute each flow instance

A plan is a sequence of steps that specifies the transmission sequences that may be used to forward a flow's packets from its source to the destination

LCP planner

FCP planner





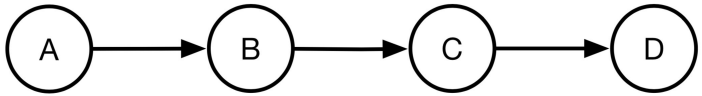
Design: Planning

LCP Planner:

1. Each link is assigned to transmit RL times
2. Each step of a plan contains a single transmission
3. The order of transmissions dictated by the plan's step respect hop-by-hop forwarding constraints

Link-Centric Policy (R_L=2):

S[0]	S[1]	S[2]	S[3]	S[4]	S[5]
(AB)	(AB)	(BC)	(BC)	(CD)	(CD)



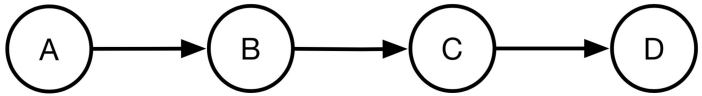
Design: Planning

FCP Planner:

1. Each link is assigned to transmit RF times
2. One or more, possible conflicting, transmissions are assigned in each step
3. Hop-by-hop forwarding constraints are relaxed to allow packets to follow different transmission sequences

Flow-Centric Policy (R_F=3):

***S*[0]**	***S*[1]**	***S*[2]**	***S*[3]**	***S*[4]**
(AB)	(AB)	(AB)		
	(BC)	(BC)	(BC)	
		(CD)	(CD)	(CD)



Design: Runtime Adaptation for FCP

Local and lightweight transmission adaptation mechanism

ACK to trigger subsequent transmissions

Possibility of disagreement about the success of a transmission

- Problem: ACK lost
- Solution: Differences in time slot and monitoring

FCP allows retransmissions redistribution based on errors due to the quality of the links, whereas LCP (employs simple ARQ) does not

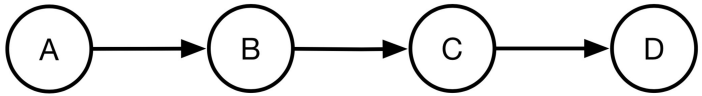
Design: Configuring Retransmissions

Linear search procedure R_L, R_F to meet end to end reliability

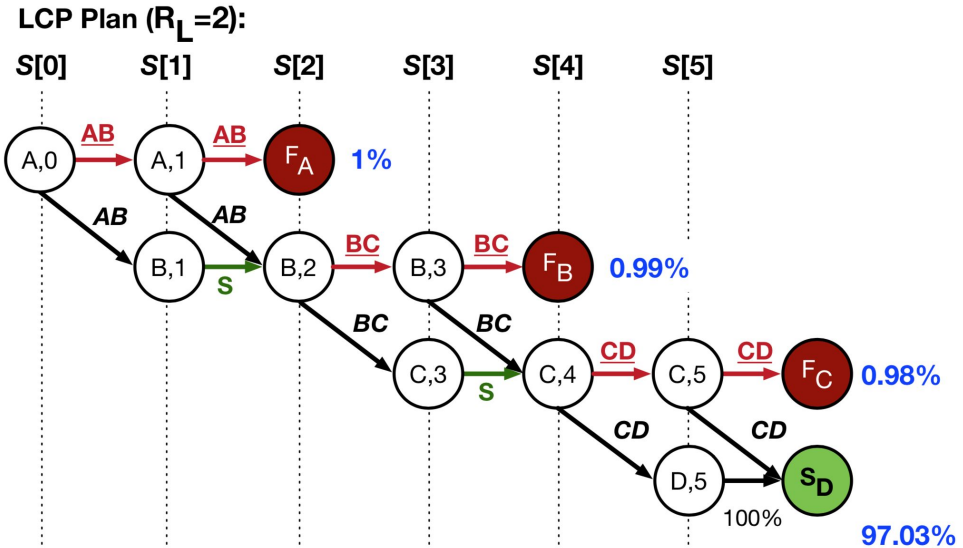
Likelihood of delivering a packet to its destination after executing a concrete plan?

Modeled as Markov Chains

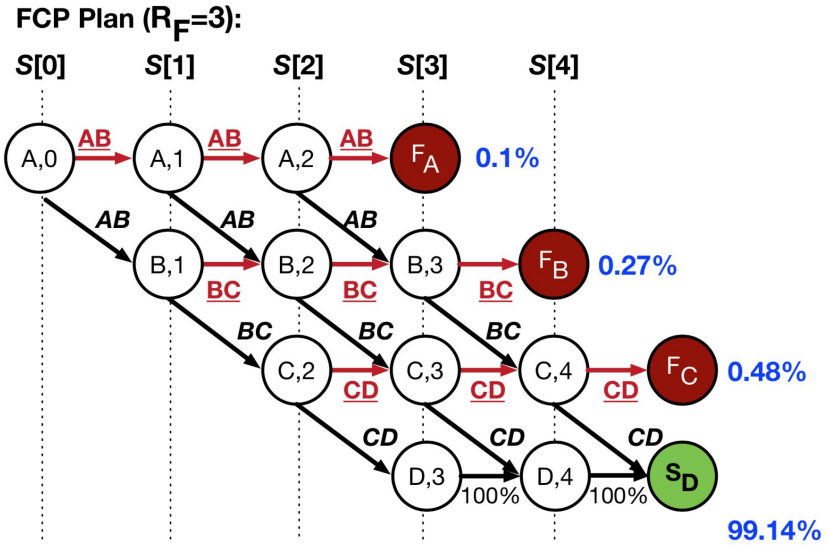
- MC state: (Node, step)
- Transmit successfully, transmit unsuccessfully or sleep



Design: Configuring Retransmissions



(a) Markov Chain for LCP



(b) Markov Chain for FCP

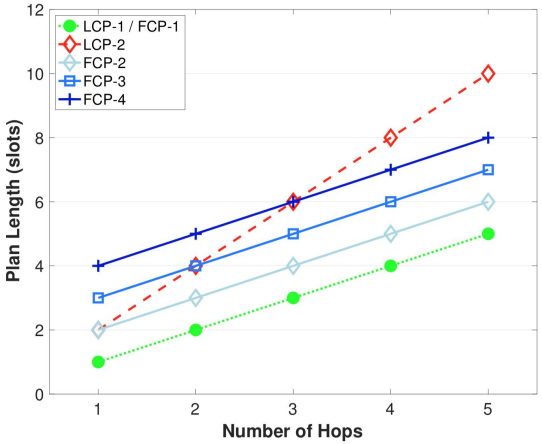
Design: Empirical Results Single Flows

Shows:

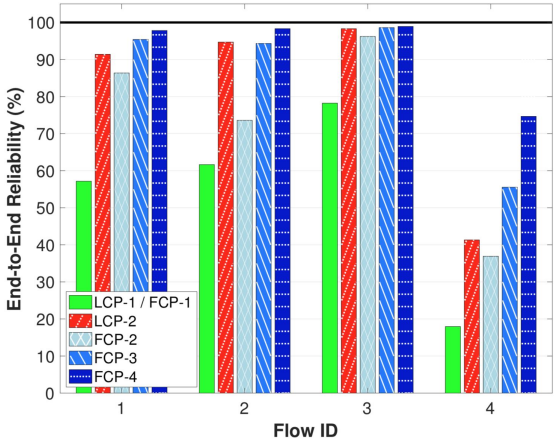
1. FCP has the ability to adapt its retransmissions which results in significant performance improvements over LCP
2. Effectiveness of the MC model approach for configuring retransmissions

16 node Network running TSCH based on LCP and FCP plans with different R_F and R_L

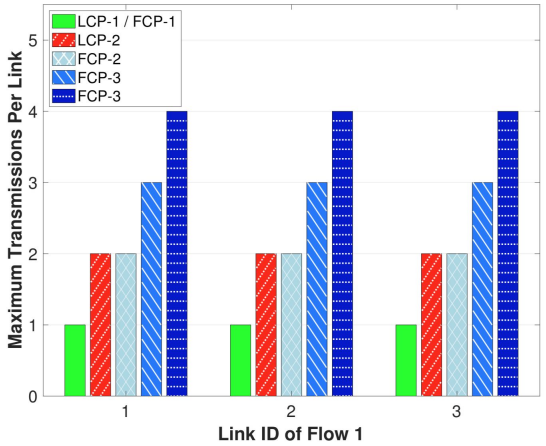
Design: Empirical Results Single Flows



(a) Plan length



(b) Reliability for 3-hop flows



(c) Flow 1 max used transmissions

Steps vs Hops

(FCP allows more retransmissions in less number of steps for a concrete number of hops)

Reliability vs Model

(FCP has similar or higher reliability than LCP with much less number of steps)

Transmissions vs Model

(FCP has more maximum number of retransmissions than LCP because it can dynamically re-allocate them)

Design: Handling Multiple Real-time Flows

When we have the plan for each single flow we can handle the multiple flows

The scheduler determines the slot and channel for each step of each plan

The scheduler ensures:

- No transmission conflicts occur even as adaptation mechanisms dynamically reallocate retransmissions
- Transmissions in consecutive slots use different channels

Design: Handling Multiple Real-time Flows

There is a difference between LCP and FCP

Because FCP can schedule multiple transmission on each slot it has less concurrency between flows

In exchange the schedule need less slots

Experiments

We need to do tests because

1. The issue with concurrency must be estimated
2. Subtle errors in our assumptions might affect performance.
    - Complex systems are hard to predict

Experiments

Want to find:

1. Tradeoff between plan length and concurrency (Simulator)
2. Real-time capacity (Simulator)
3. Empirical data for reliability. (Testing on 16 nodes)

Topology

Control loop

Base station in the middle

Rest: random if sensor or actuator (In pairs)

2:3:5 ratio

Metrics

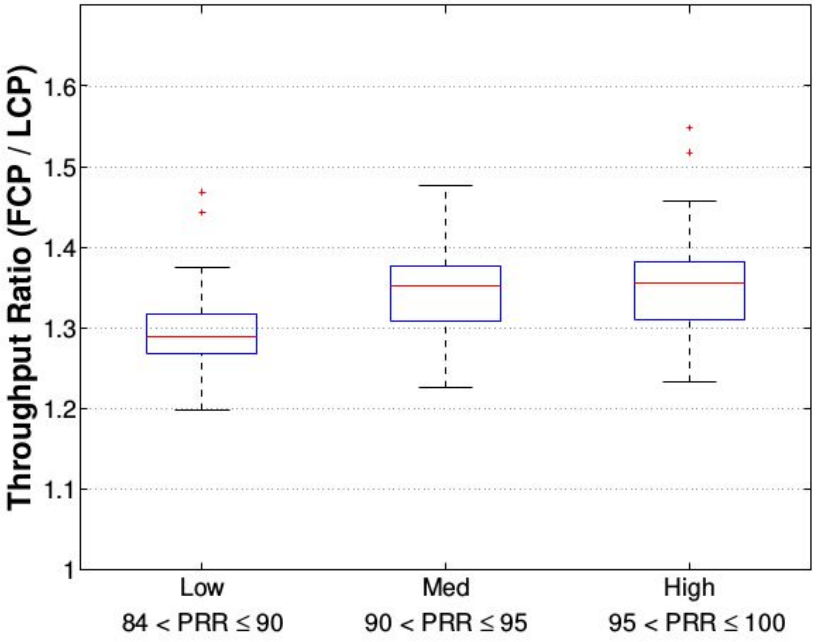
Throughput

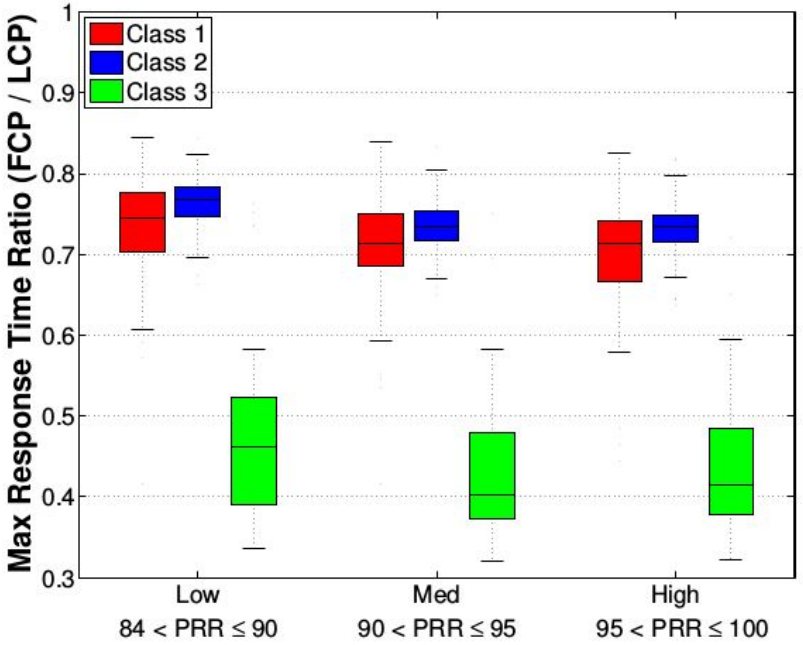
Real-time capacity

Response-time

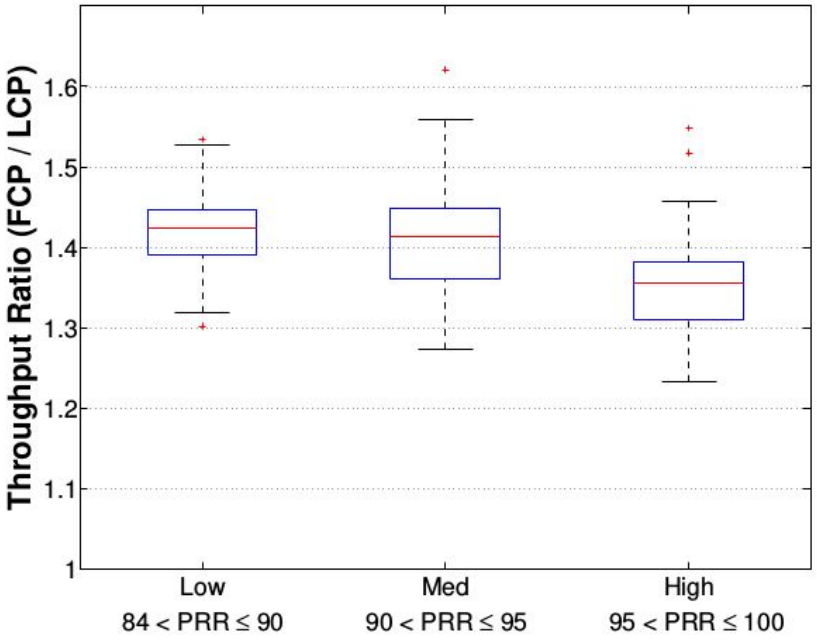
(Reliability)

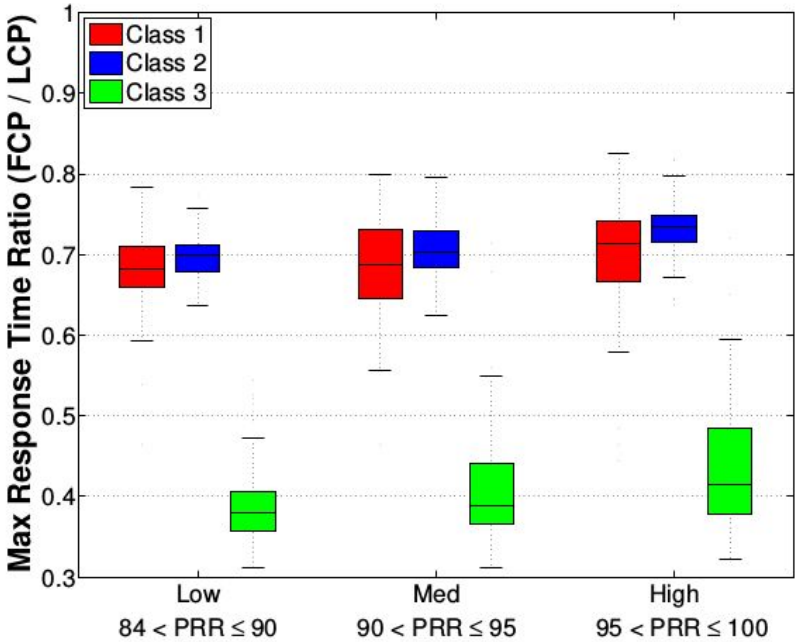
Results of simulations (UFM)





Results of simulations (LFM)





Results of simulations (UFM)

- FCP has less transmission conflict delay
  - The shorter plans might outweigh the loss in concurrency

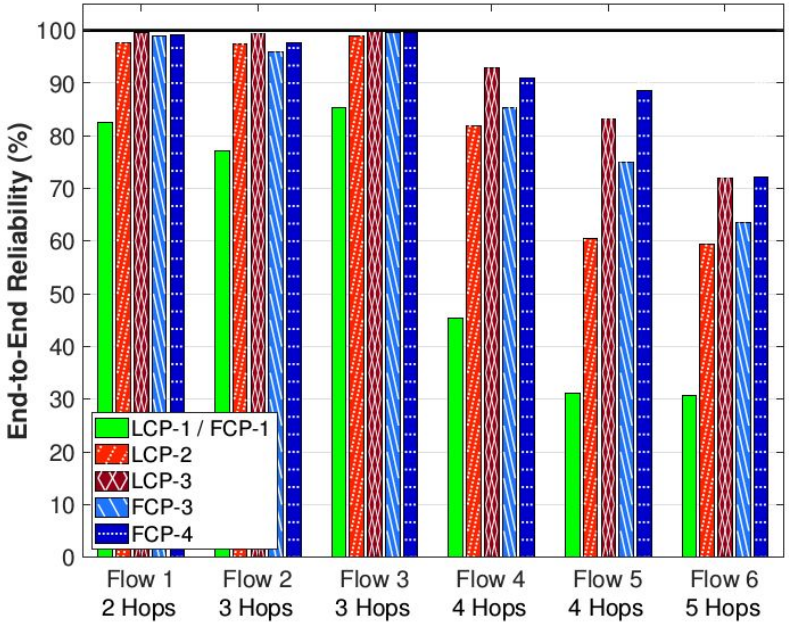
Testbed evaluation

16 nodes, with 6 different flows of different lengths

- 2 hops (1 flow)
- 3 hops (2 flow)
- 4 hops (2 flow)
- 5 hops (1 flow)

(They did not mention the topology)

Empirical results



The paper’s conclusion

The shorter plans outweigh the loss in concurrency

The increase in performance can be traded in for better reliability

Lightweight with only local coordination

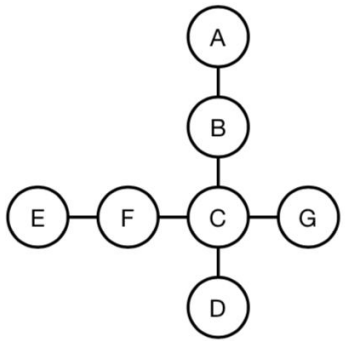
Criticisms (Link)

Does not address broken links

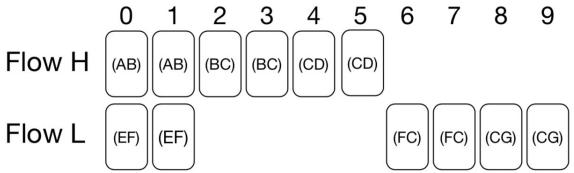
Half-duplex link is it justified?

Criticisms (Schedule)

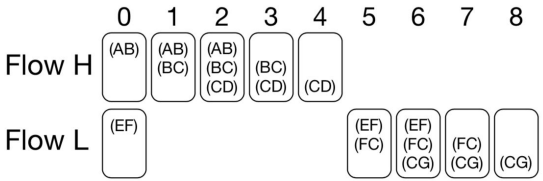
LCP more concurrent and FCP smaller is on a particular convenient example



(a) Topology



(b) LCP-2 Schedule



(c) FCP-3 Schedule

Criticisms (Tests)

The empirical tests had 16 nodes

Simulator: Data gathered form a 41 node network

- Normal use-case for WHART can be >1000 nodes.

No data on error-correlation

Unknown topology

- Can skew the results

Criticisms (General)

Need to be careful with the time-synchronization of node

How do they consider the secondary path on WHART in the schedule?

Conclusion

Results seem promising

Not mature for high-reliability

- Further revision
- More testing

Implement in non-critical systems