“Pulse-SDN: Pulse-Coupled Software Defined Networks for Circuit Switched Industrial Control Area Networks”

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MOTIVATION

Great potential of Software Defined Control Area Networks (SD-CAN) to better adapt protocols to CAN latency requirements

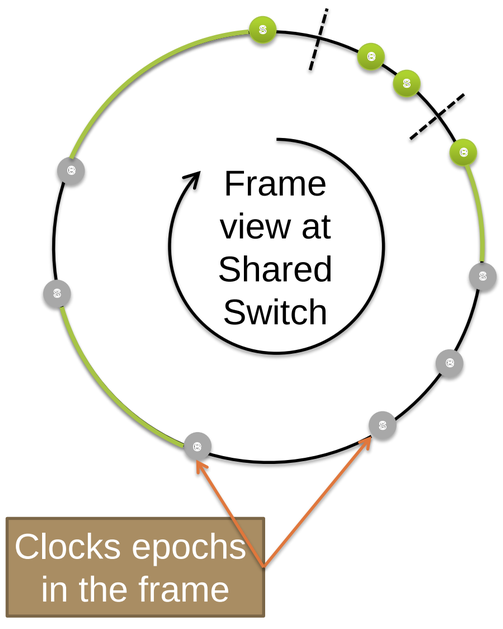
- Circuit switched communications better for CAN than packet switching
- Challenge: complexity of deployment, adaptation, failure recovery

- Idea: Merge in SDN the network and medium access sub-layer solving a multiple access problem over a shared multi-hop path
- The problem is analogous to finding conflict free Time Division Duplex (TDD) schedules in wireless networks

PROPERTIES OF NEW CAN-SDN PROTOCOL

- Minimal end to end latency + no queues at forwarding nodes → instantaneous reception and forwarding of messages
- Fully distributed + simple local computations -> Scalable
- Can co-exist with legacy protocols (with queues) as long as this protocol always has priority (i.e. with IEEE802.1p)
- Traffic flow is controlled by design and is allocated proportionally to demand
- Routes can change dynamically, but not on an active connection
- Resilient to node failures, Self-healing (inspired by biological networks).

BASIC IDEA



- At each node has a “fine” clock measures the time that elapses between one frame transmission and the next
- All nodes schedule is kept via two coarse clock with period = L slots: the “start” slot clock and the “end” driven for each connection
- Each SDN switch has several clocks that mirror the position of all transmitters using a path that crosses that switch

scheduling *synchronization*

$$\Phi_v(t) = s_v(t) + \varphi_v(t) \pmod L$$
$$\Phi'_v(t) = e_v(t) + \varphi_v(t) \pmod L$$

- Each time a clock reaches L it sends a control packet called *beacon*
- Every switch along the path intermediately acknowledges and forwards the beacon to the next switch in the route (like domino effect)
- Both coarse clock and fine clock for communications that are are updated upon receiving a beacon from another communications

Fine Clock update: Every time a beacon is received at time $r_v^{(s)}$ at node v with an estimated travel time of $\hat{t}_{v,c}$, node v updates

$$\hat{\varphi}_c = \varphi_c(r_v^{(s)}) - \frac{\hat{t_{v,c}}}{T}$$

$$\varphi_u(\hat{t}_{c,u}^{(s)+}) = \begin{cases} \varphi_u(\hat{t}_{c,u}^{(s)}), & \Phi_u(\hat{t}_{c,u}^{(s)}) \le \delta_{\text{ref}}, \\ \min\{(1+\alpha)\varphi_u(\hat{t}_{c,u}^{(s)}), 1\}, & \text{else.} \end{cases}$$

The refractory period δ_{ref}, is set based on the noise in Time of arrival of a pulse, i.e. for a 125MHz Ethernet channel and SNR of 30dB is 10ns

Coarse Clock update

- In addition when a node is receiving a start pulse from its successor this node updates its coarse clock:
- Depends on: -The position of the nodes predecessor
  - The nodes demand for communication D_v
  - An transmission guard space δ

$$s_v^{target}(t) = \frac{(D_v+\delta)}{(D_v+2\delta)} e_{pre(v)}(t) + \frac{\delta}{(D_v+2\delta)} s_{suc(v)}(t)$$
$$e_v^{target}(t) = \frac{(D_v+\delta)}{(D_v+2\delta)} s_{suc(v)}(t) + \frac{\delta}{(D_v+2\delta)} e_{pre(v)}(t)$$

SAMPLE NETWORK

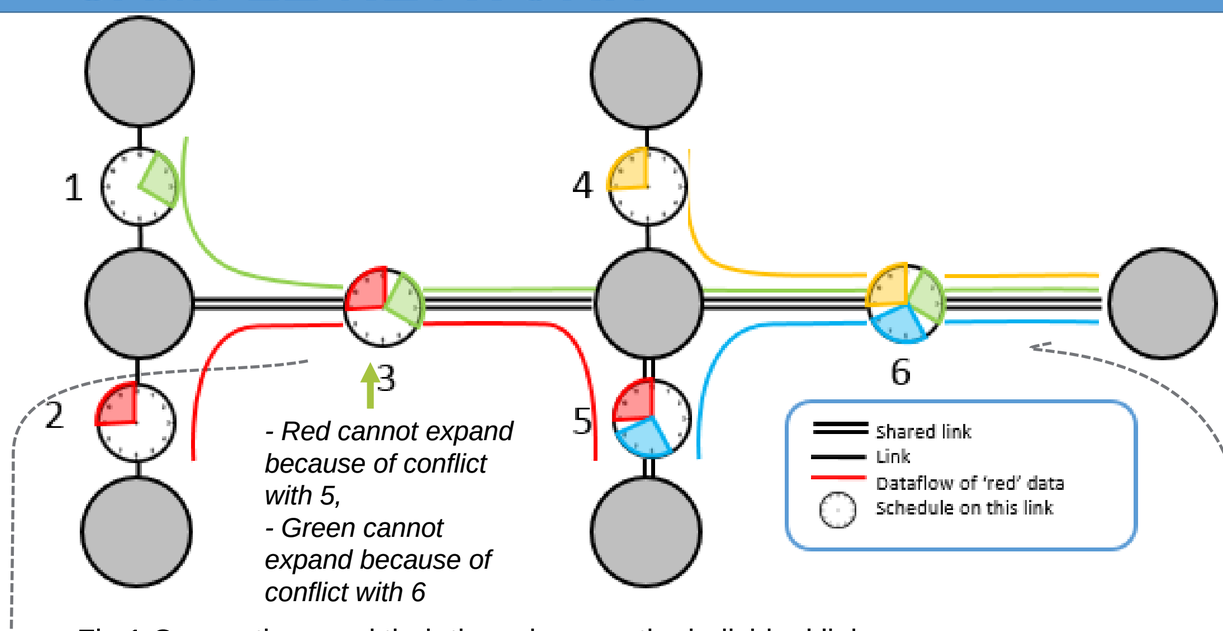


Fig.1 Connections and their time share on the individual links

- Connections are maintained by the data source that is controlling when to send data in the frame and switches mirror source clocks
- Each link is peer to peer, used for a nodes own and forwarded data
- Links that are used my multiple connections create conflicts.
  - our protocol resolves such that there is only one connection active at a time (TDD)
  - A connection always has a two-way path exclusively allocated at a certain interval of the frame → circuit switched communications

SIMULATION RESULTS

- ***Simulation:*** *Topology as in Fig.1, each connection has the same demand 5, delta 1, 120 slots, 20 iterations coupling factor a=0.03, b=0.7*

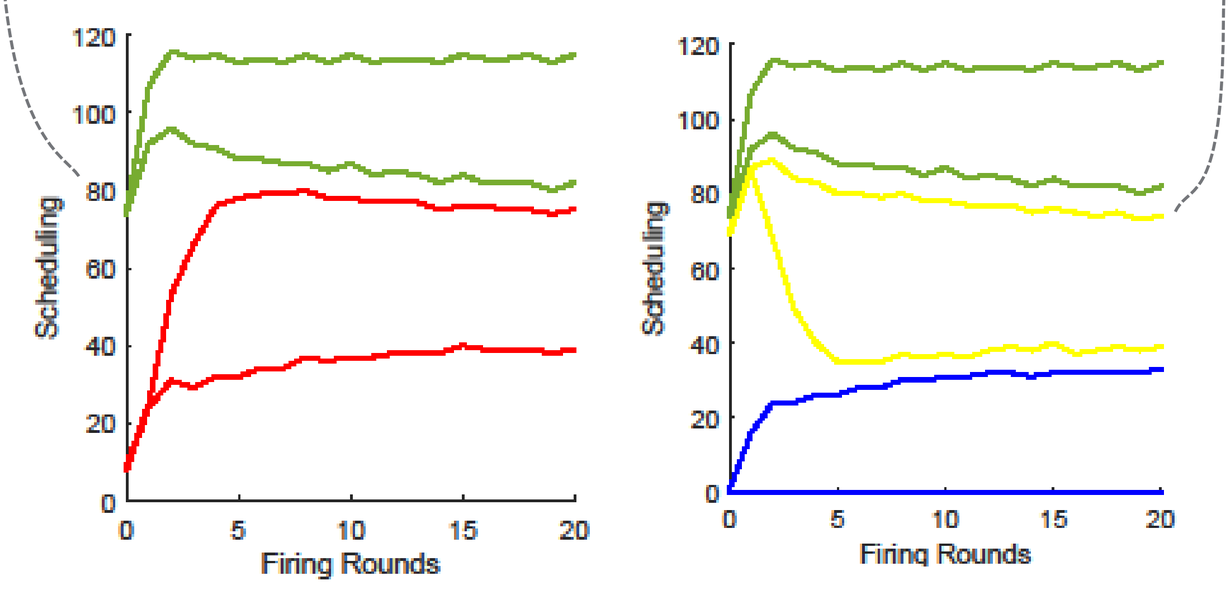


Fig.2 Exemplary scheduling Result of link 3 (left) and link 6 (right) for topology in Fig.1

- Scheduling Results show that the proposed algorithm is converges to the results indicated in Fig. 1.
- We successfully achieve exclusive accesses for each link on each connection
- Each connection gets its fair share of the available communication time per frame (latency = 1 frame)
- The ‘wobbles’ in the graph result due to dithering in the scheduling update that stabilizes the protocol selection of the start and end slots
- Simultaneously all nodes acquire global synchronization (not shown)

BROADER IMPACT/FUTURE EFFORTS

- Impact in all scenarios where latency is important and the traffic patterns are predictable such as industrial control, sensor networks, telephone and video communications.
- Impact at very high speed connections where buffering traffic at each switch is a burden
- Study the protocol on a large network with thousands of connections
- Implement the protocol in an SDN network to prove real world applicability

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