Capacity of Dual-Radio Multi-Channel Wireless Sensor Networks for Continuous Data Collection

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Outline

1. Introduction
2. Network Model
3. Snapshot Data Collection
4. Continuous Data Collection
5. Simulations and Analysis
6. Conclusion

1. Introduction

- Data gathering
  - Data Aggregation, e.g. MAX, MIN, Average
  - Data Collection
    - Snapshot Data Collection
    - Continuous Data Collection
- Network Capacity
  - Multicast/Unicast/Broadcast Capacity
  - Snapshot Data Collection Capacity
  - Continuous Data Collection Capacity

- Radio Confliction Problem
  - Single Radio vs. Dual-Radio
- Channel Interference Problem
  - Single Channel vs. Multi-Channel
- Protocol Interference Model

Our Contributions

- An order-optimal *multi-path scheduling* algorithm for snapshot data collection
  - Lower bound capacity: $$\frac{W}{\frac{3.63}{H}\rho^2 + o(\rho)}$$
- Snapshot data collection algorithms + Pipeline = Continuous data collection algorithms?
- A *pipeline scheduling* algorithm for continuous data collection
  - Lower bound capacity: $$\begin{cases} \frac{nW}{12M(\frac{3.63}{H}\rho^2 + o(\rho))}, & \Delta_e \le 12 \\ \frac{nW}{M\Delta_e(\frac{3.63}{H}\rho^2 + o(\rho))}, & \Delta_e > 12 \end{cases}$$

2. Network Model

- Network model
  - n sensors, $G=(V, E)$, $r=1$, $\rho \geq r$
  - Dual-Radio, H channels, $t=b/W$
- CDS-based Routing Tree
  - Breadth-First-Search (BFS) tree
  - Connected Dominating Set (CDS) [1]
    - Dominator: Maximal Independent Set (MIS)
    - Connector
  - Lemma 1 [1]: $\beta_r \leq \frac{\pi}{\sqrt{3}} r^2 + (\frac{\pi}{2}+1) r + 1$

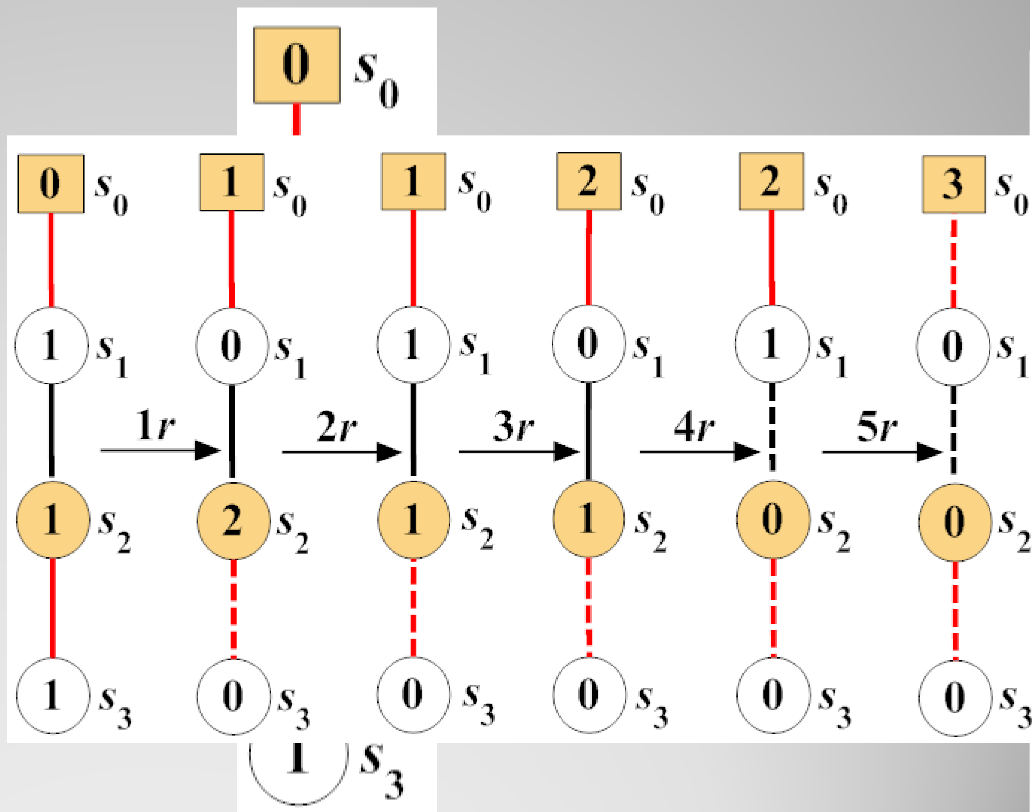
- Vertex Coloring Problem

  - Lemma 2 [1, 20]: $\chi(G) \leq 1 + \delta^*(G)$ $(\delta^*(G) = \max_{U \subseteq V} \delta(U))$ and a vertex coloring scheme, called *first-fit coloring*, for *G* using at most $1 + \delta^*(G)$ colors can be found in polynomial time.

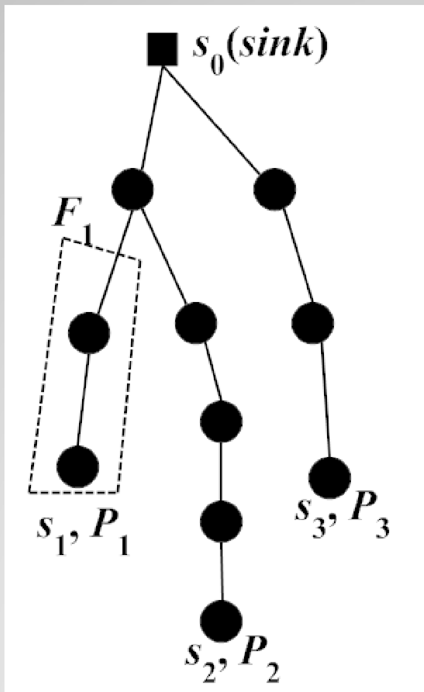
  - Given a link set *A* of *T*, if the tail (resp. head) of every link in *A* is a dominator, then $\delta^*(A) \leq \beta_{\rho+1} - 1$ (Lemma 3 [1]).

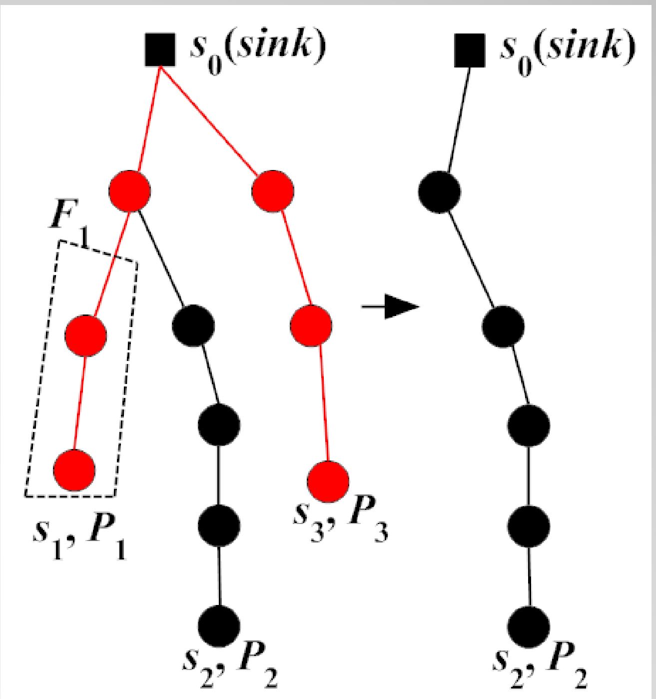
3. Snapshot Data Collection

- Multi-Path Scheduling
  - Intra-path *P*:
    - $P_o(P_e)$: links on *P* whose heads (tails) are dominators and whose tails have at least one packet to be transmitted
    - Step 1: in an odd round, schedule every link in P_o once.
    - Step 2: in an even round, schedule every link in P_e once.



- Inter-path
  - Schedule multiple paths as long as there is no interference

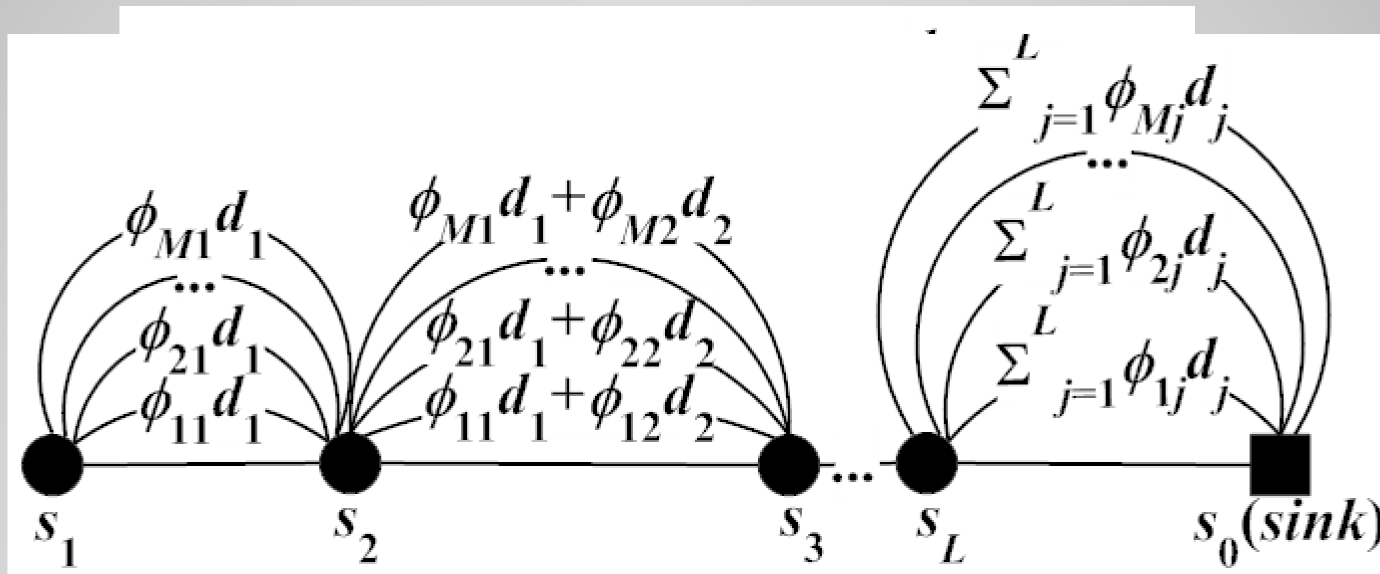




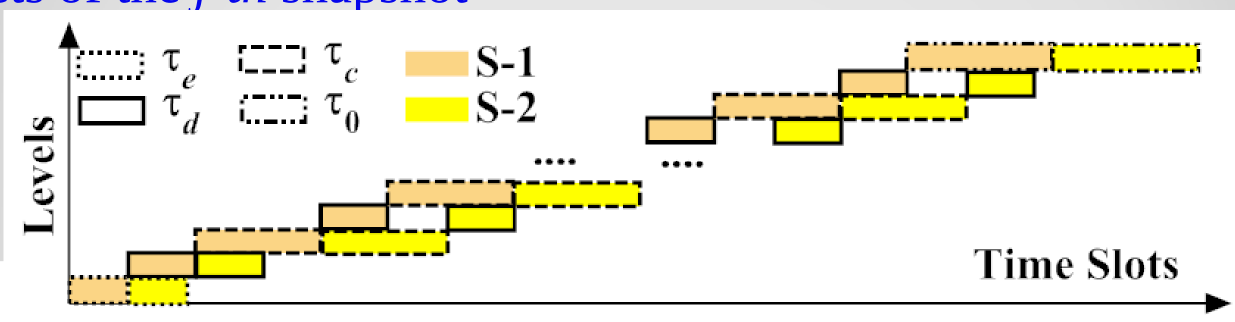
- Capacity Analysis
  - For a path of length L, it takes at most $2L$-1 rounds to collect all the packets on this path (Lemma 4).
  - A round has at most $\left\lceil \frac{\beta_{\rho+1}}{H} \right\rceil$ time slots (Lemma 5).
  - The capacity of the *multi-path scheduling* algorithm is at least $\frac{W}{\frac{3.63}{H}\rho^2 + o(\rho)}$, which is order optimal.
  - Better than the latest result, which is $\frac{W}{8\rho^2}$.
- Discussion
  - Snapshot data collection algorithms + pipeline = continuous data collection algorithms?

4. Continuous Data Collection

- A *pipeline scheduling* algorithm based on *compressive data gathering* (CDG) [3]
- CDG



- Pipeline Scheduling
  - Partition the nodes in T into levels: D_e, $D_{L'}$, $C_{L'-1}$, …, D_1, C_0, $D_0=\{s_0\}$
  - All the transmissions are conducted in the CDG way.
  - For the *j-th* snapshot
    - Schedule D_e to transmit the *j-th* snapshot
    - Schedule $D_l(1 <= l <= L')$ (resp. $C_l(1 <= l <= L'-1)$) to transmit the *j-th* snapshot after the nodes in D_l (resp. C_l) have received all the packets of the *j-th* snapshot from their children nodes
    - The sink restores the data of the *j-th* snapshot in the CDG way
  - Each level starts to transmit the (*j+1*)-*th* snapshot after it transmits all the packets of the *j-th* snapshot



- Capacity analysis
  - *A* is a set of links scheduled simultaneously in the pipeline scheduling algorithm, then $\delta^*(\Re(A)) \leq 2\beta_{\rho+2} - 1$ and *A* can be scheduled with $\left\lceil \frac{2\beta_{\rho+2}}{H} \right\rceil$ Super Time Slots (STSs) (Lemma 6, Lemma 7).

  - To collect the first snapshot, the number of time slots used is at most $M\left\lceil \frac{2\beta_{\rho+2}}{H} \right\rceil(\Delta_e + 15L' + 1)$ (Theorem 2).

- Theorem 3: the number of time slots used to collect *N* continuous snapshots is at most

$$\begin{cases} M\left\lceil \frac{2\beta_{\rho+2}}{H} \right\rceil (\Delta_e + 15L' + 12N - 11) & \Delta_e \leq 12 \\ M\left\lceil \frac{2\beta_{\rho+2}}{H} \right\rceil (N\Delta_e + 15L' + 1) & \Delta_e \leq 12 \end{cases}$$

- Theorem 4: the lower bound capacity of the pipeline scheduling algorithm is

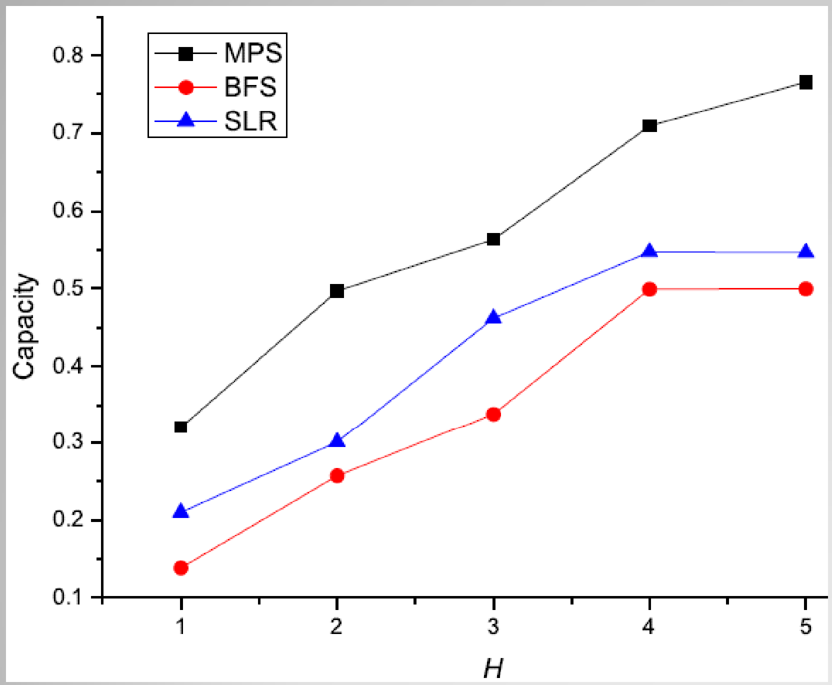
$$\begin{cases} \frac{nW}{12M(\frac{3.63}{H}\rho^2 + o(\rho))}, & \Delta_e \leq 12 \\ \frac{nW}{M\Delta_e(\frac{3.63}{H}\rho^2 + o(\rho))}, & \Delta_e > 12 \end{cases}$$

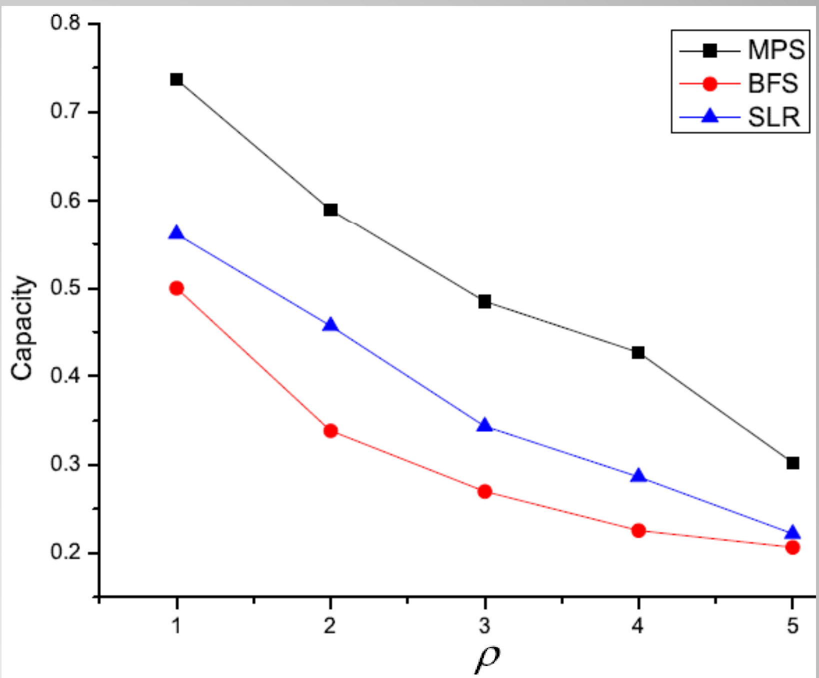
5. Simulations and Analysis

- Simulation settings
  - Nodes: randomly distributed, dual-radio, communication radius is normalized to 1
  - TDMA
  - Band width: normalized to 1
  - Packet size: normalized to 1
  - Channels are orthogonal

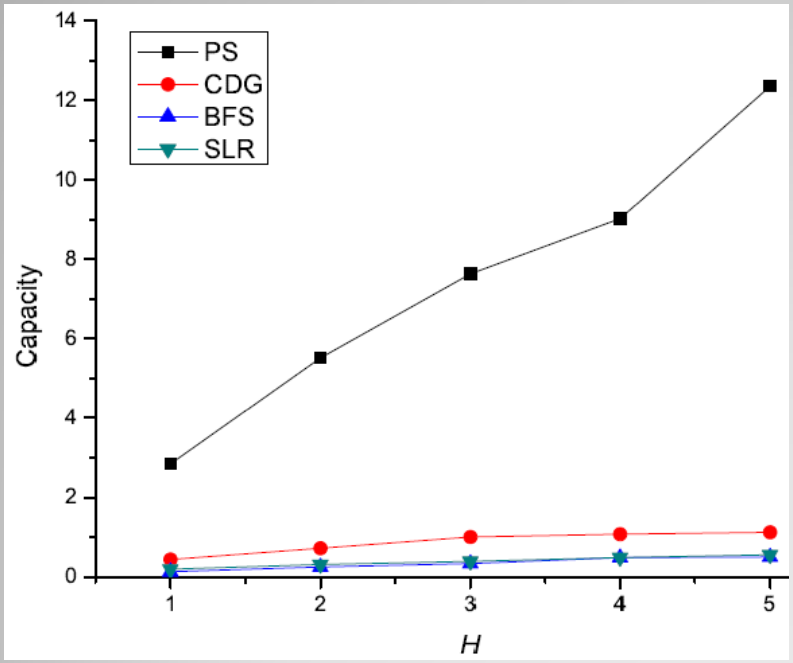
- Compared algorithms
  - Snapshot data collection
    - BFS (Infocom 2010), SLR (Infocom 2007), **MPS**
  - Continuous data collection
    - CDG (Mobicom 2009), BFS, SLR, **PS**

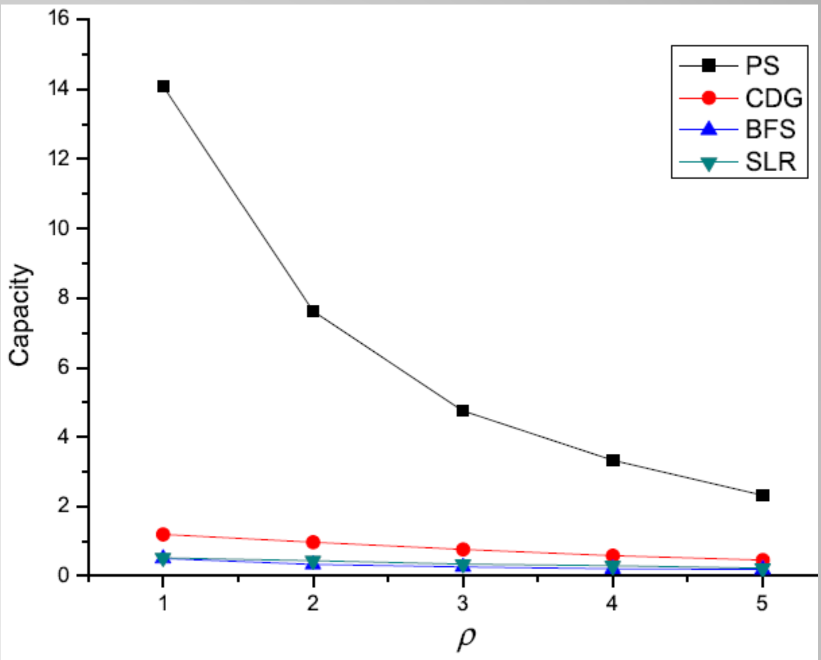
Performance of MPS





Performance of PS





THANK YOU !