



Delay Analysis of STDMA in Grid Wireless Sensor Networks

Ichrak Amdouni, *Cedric Adjih*, Pascale Minet (Inria, France)
Thierry Plesse (DGA, Bruz, France)

Outline

- Motivation, assumptions and problem statement
- TDMA with spatial reuse (STDMA):
 - Impact of TDMA scheduling on routing delay
- Routing delay analysis (model, results)
- Conclusion

1

MOTIVATION, ASSUMPTIONS AND PROBLEM STATEMENT

Motivation

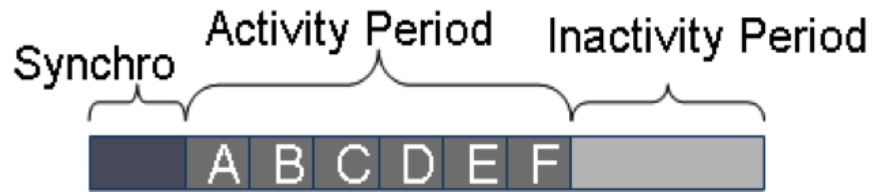
- Military Sensor Networks
 - Funding DGA/ASTRID (GETRF)
- Application:
 - Area surveillance
- Requirements:
 - Large scale wireless sensor networks
 - Battery-operated
 - Deterministic; reliable, multiple sinks



(source: from GreenObs, IOT Tech Center, TNLIST)

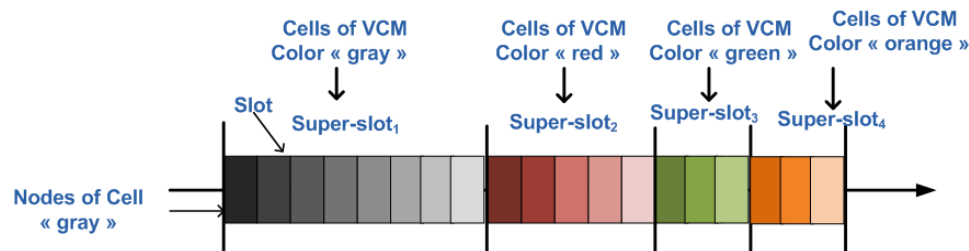
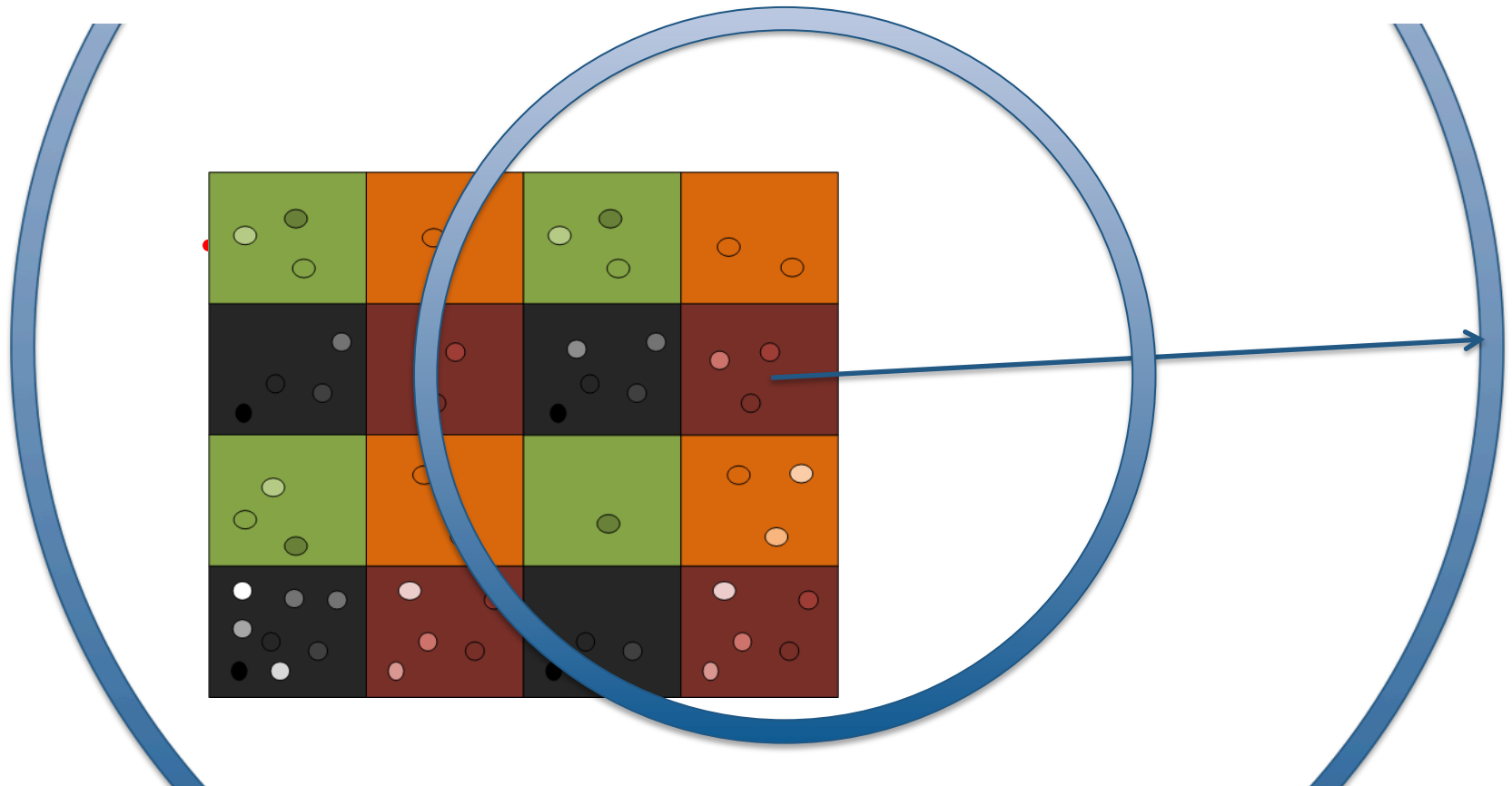
TDMA-based WSNs scheduling

- TDMA: Time Division Multiple Access
- Nodes in the same area transmit each in turn
 - Time is divided into cycles (frames) themselves divided into slots (colors)



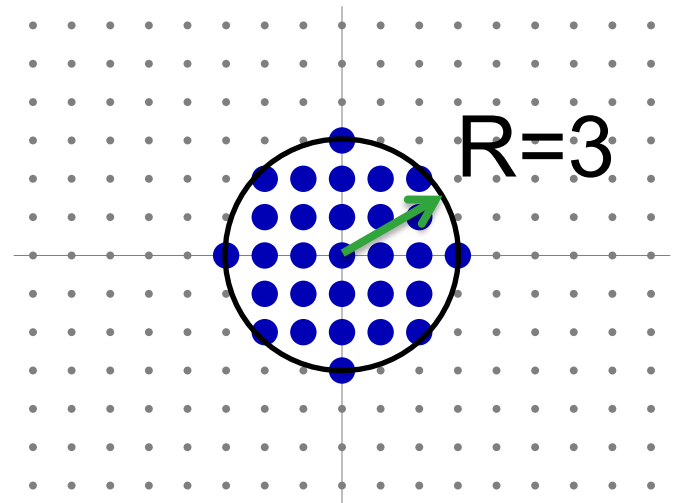
- Each node has a time slot for transmission
 - No collisions
 - Energy saving

From Large Scale Networks to Grids



Network model: Ideal Grid Topologies

- Large scale networks
- Topology = Grids:
 - regular topologies
 - infinite grid
- Unit disk graph model, range R
- How to do TDMA on an large/infinite grid?
 - spatial reuse : STDMA
 - « Vector-based Coloring Method » (VCM) [15]



Problem Statement

- Scaling Law: what is the asymptotic performance of (S)TDMA in networks ?
 - For end-to-end routing delays
 - With VCM (STDMA)
- Useful: for dimensioning networks, etc.

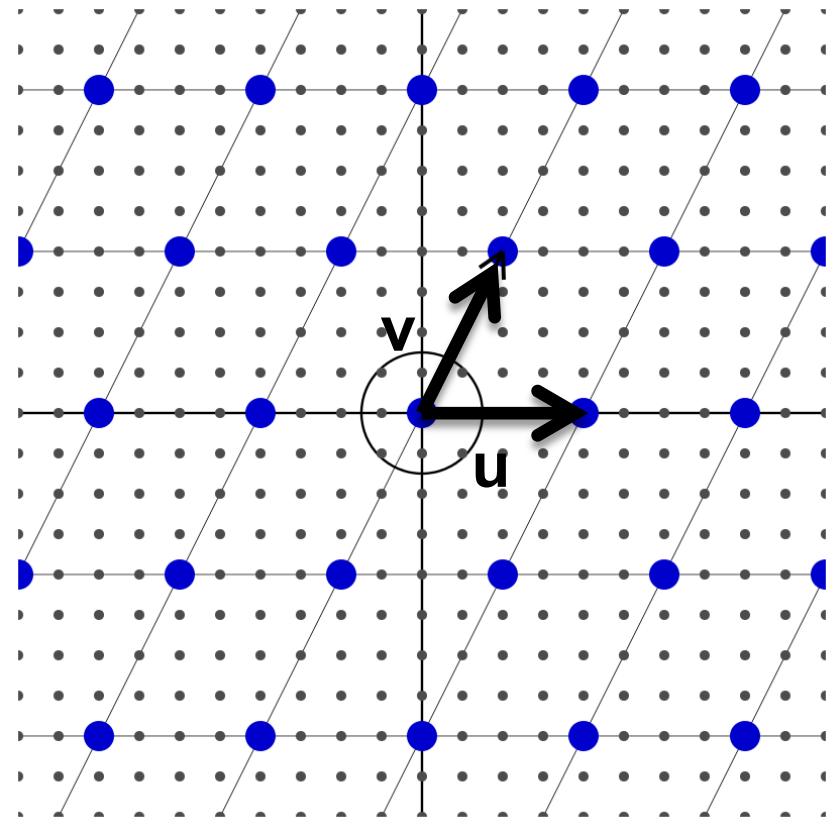
2

ROUTING DELAY AND COLOR ORDERING (SCHEDULE)

VCM: Vector-based Coloring Method

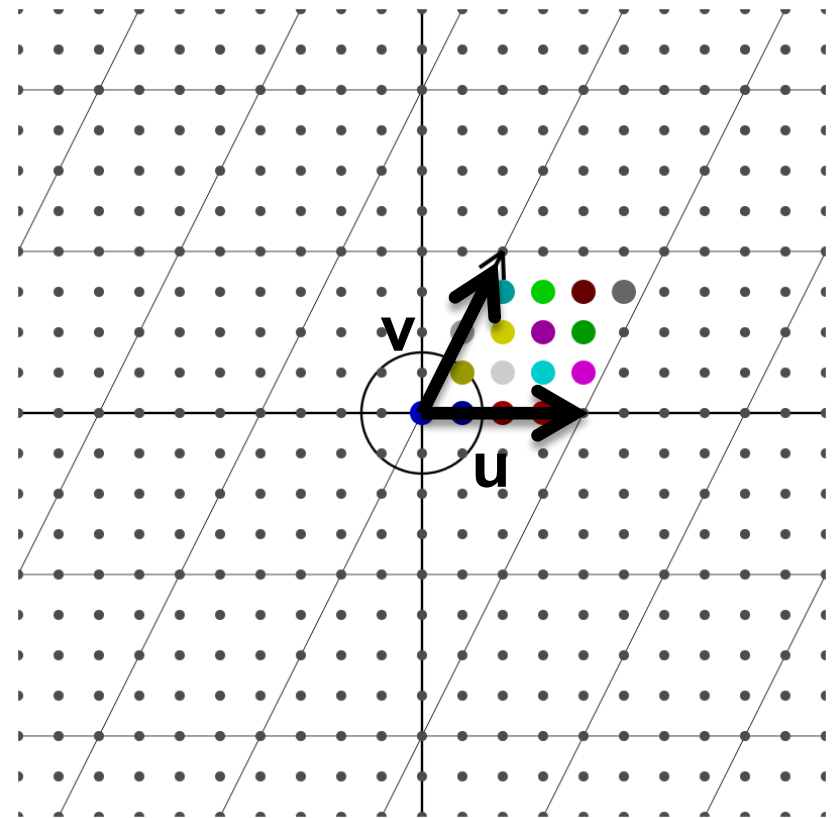
- Efficient TDMA on a large networks: spatial reuse (STDMA)
- **Prior work VCM [15] for Grid Networks**

1. Two generator vectors u, v :
lattice of non-interfering nodes
(protocol model: h-hop coloring)



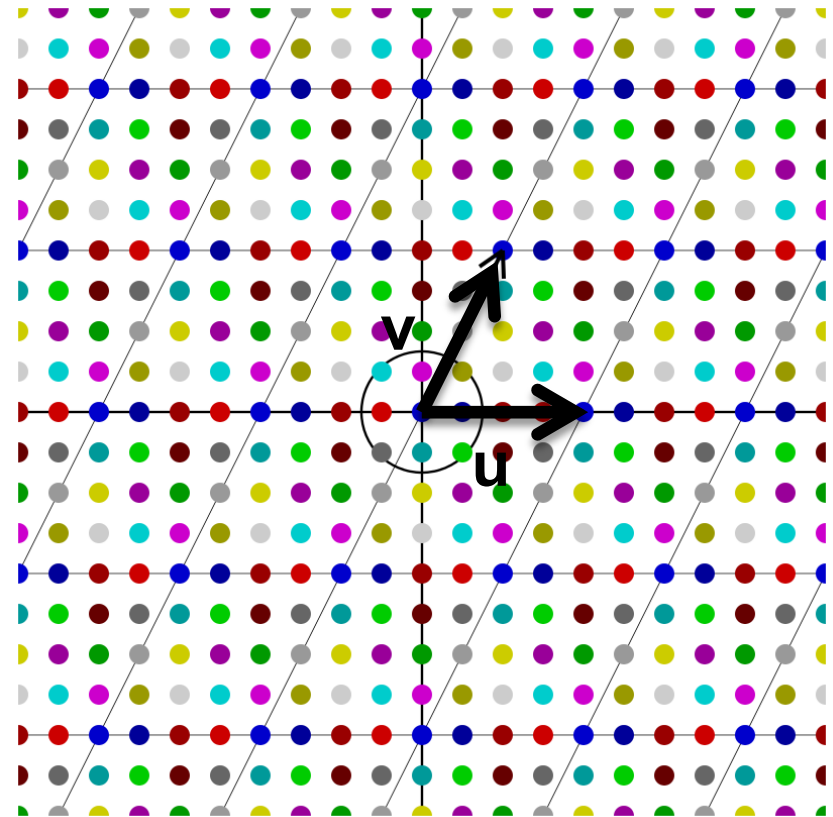
VCM: Vector-based Coloring Method

- Efficient TDMA on a large networks: spatial reuse (STDMA)
- **Prior work VCM [15] for Grid Networks**
 1. Two generator vectors u, v :
lattice of non-interfering nodes
(protocol model: h-hop coloring)
 2. Nodes in base parallelogram
are assigned different colors



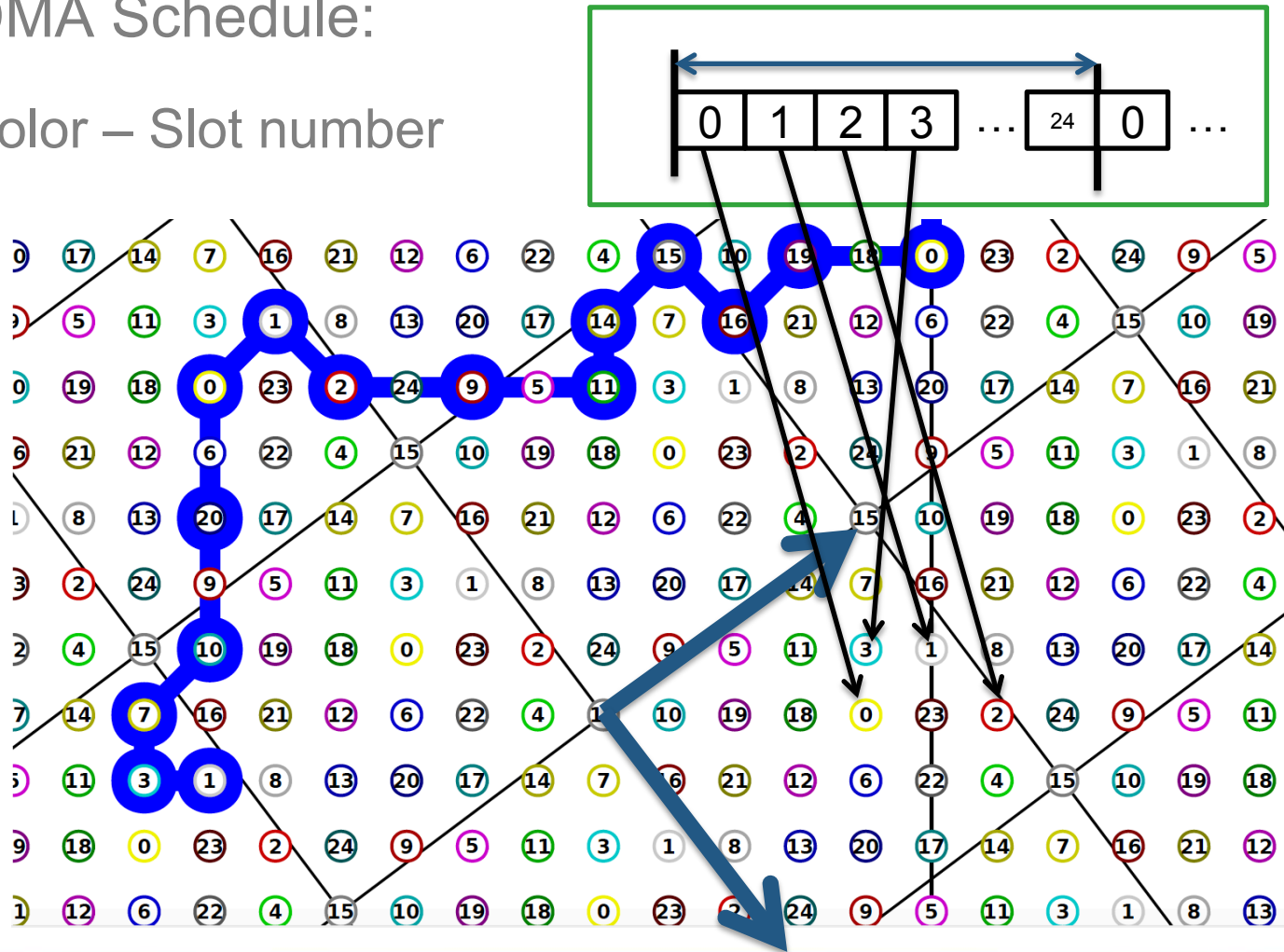
VCM: Vector-based Coloring Method

- Efficient TDMA on a large networks: spatial reuse (STDMA)
- **Prior work VCM [15] for Grid Networks**
 1. Two generator vectors u, v :
lattice of non-interfering nodes
(protocol model: h-hop coloring)
 2. Nodes in base parallelogram
are assigned different colors
 3. By translation, all grid is colored
- (S)TDMA: one slot for each color

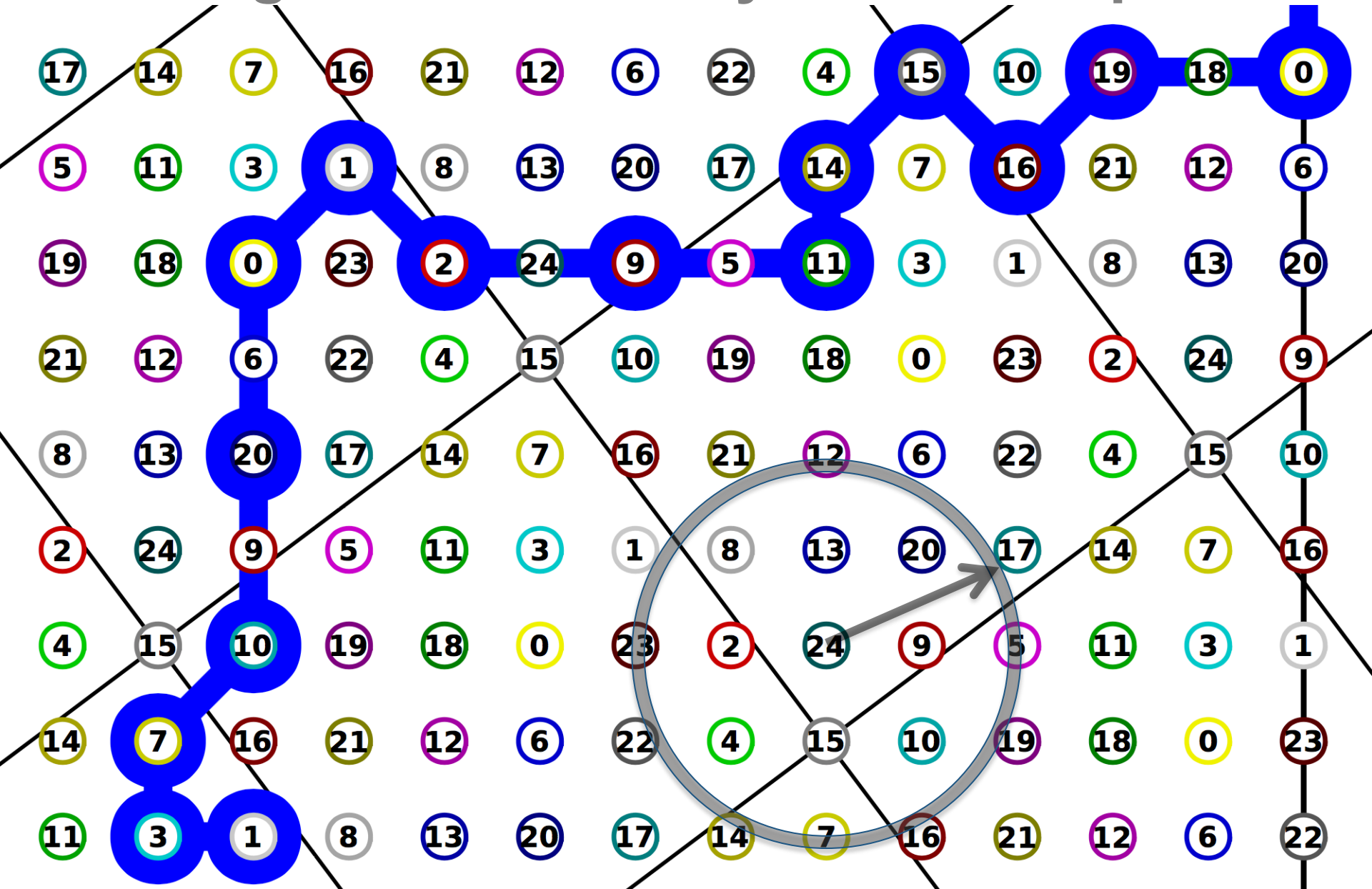


STDMA Color/Schedule Mapping

- STDMA Schedule:
 - Color – Slot number

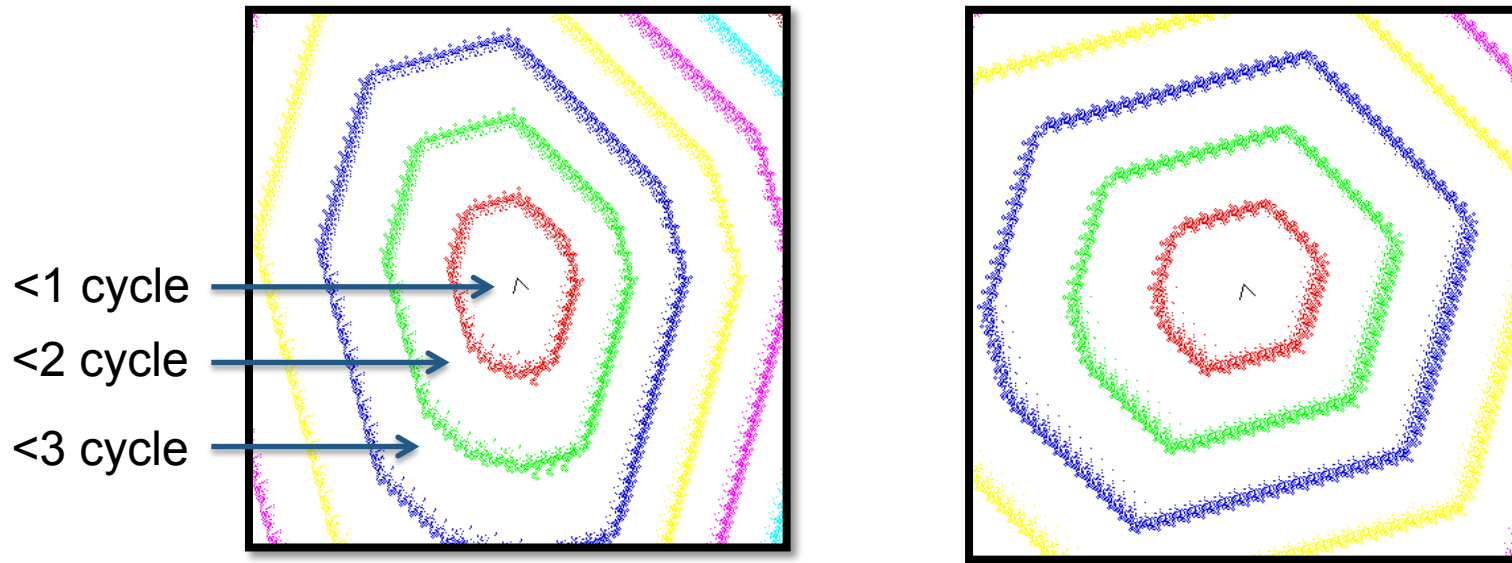


Routing: Shortest-Delay Path Example



Shortest-delay path routing with VCM

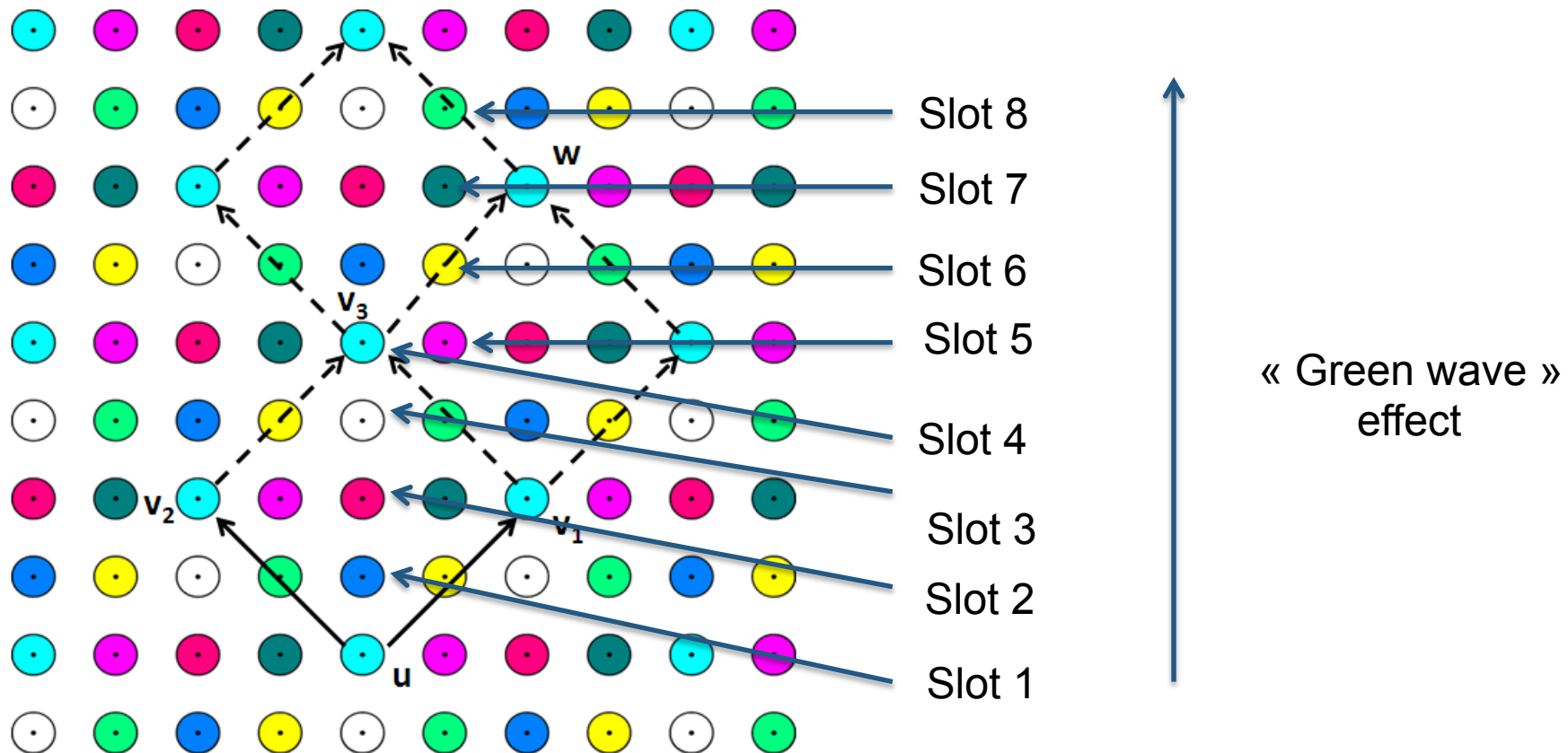
- Freedom: ordering colors in the schedule of VCM
- IRCO: “Iterated Random Color Ordering”



Set of nodes reaching center node in $< 1, 2, 3, \dots$ cycles

Effects of Color Ordering

- Introducing ordering one direction



Color Ordering

- Example with one direction
- Tradeoff:
 - Between directions
 - How many directions ?
- Limited by available colors
- Repeating the cycle only for embedded directions
- Our choice: Iterated Random Color Ordering (IRCO)

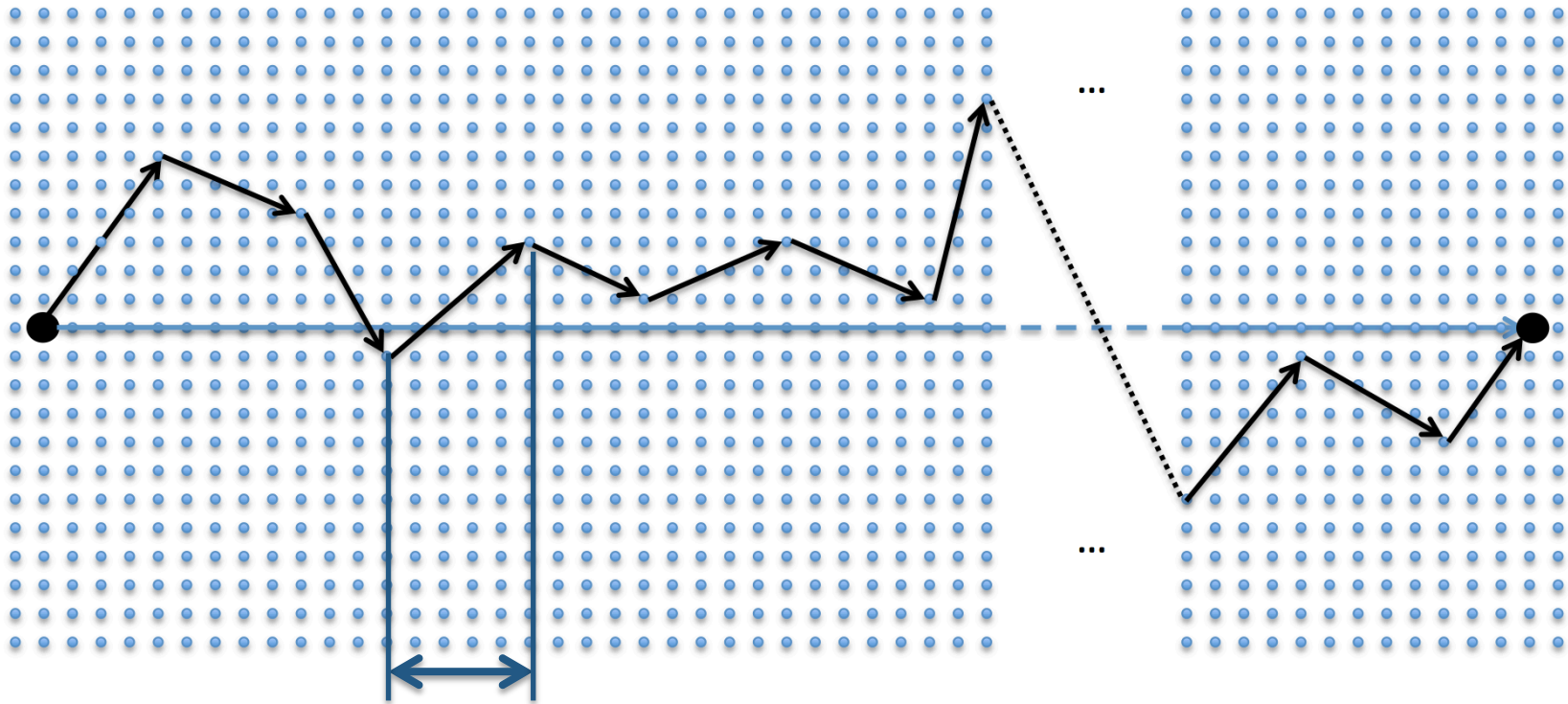


3

ROUTING DELAY MODELING

Modeling Delay on a Total Path

- Routing: source to destination (geographic routing)
- Total delay: at each step, delay, amount of progress



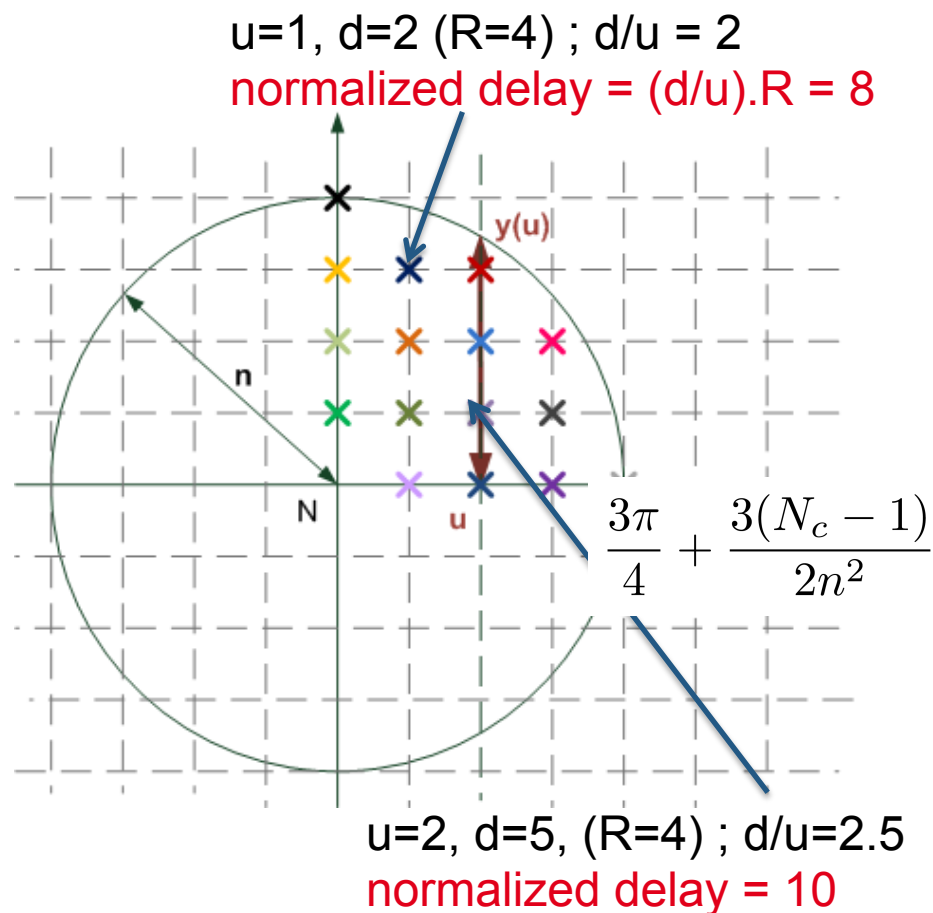
Modeling one Step

- Heuristic, greedy routing:
 - Consider one step
 - Minimize total delay
- ~ min delay/amount-of-progress

• What is the average

“Normalized Delay per range”?

- Answer: $\frac{3(N_c - 1)}{2n^2} + \frac{3\pi}{4}$
 - When the number of colors is θR^2 (when R grows)
 - Normalized delay estimate: $\frac{3}{2}\theta + \frac{3}{4}\pi$ slots to travel by R
 - This is constant, whereas the number of colors increases quadratically (min: 1)



Modeling one Step

- Every neighbor wakes up in a random slot
- Minimum normalized delay

modeled as random variable Z :

- Delay for selecting node at (u,i) is: $Y_{u,i} \triangleq \frac{c_{u,i}n}{u}$

with $c_{u,i}$ uniform in $[\alpha, \beta]$

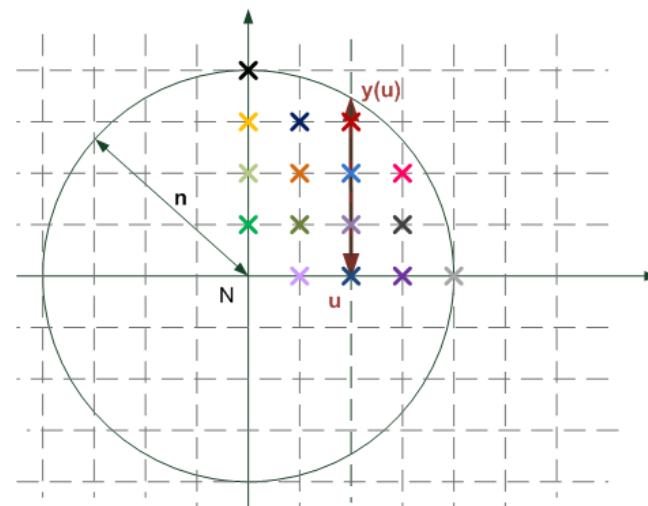
- Delay for selecting the best relay at $x=u$: $X_u \triangleq \min_{i=-y(u), \dots, +y(u)} Y_{u,i}$
- Delay for selecting the best relay at all x : $Z = \min_{u \in \{0,1,\dots,n\}} X_u$

- Cumulative distribution, approx.: $\log(1 - F_{\hat{Z}}(x)) = -\frac{2n^2}{\beta - \alpha} \left(\frac{x}{3} - \alpha \frac{\pi}{4} + O\left(\frac{1}{n}\right) \right)$

- Distribution approx.: $Pr(\hat{Z} \leq x) = 1 - \exp \left[-\frac{2n^2}{3(\beta - \alpha)} \left(x - \frac{3\alpha\pi}{4} \right) \right]$

- Distribution corresponds to $\hat{Z} - \frac{3\alpha\pi}{4}$ exponential with parameter $\lambda = \frac{2n^2}{3(\beta - \alpha)}$

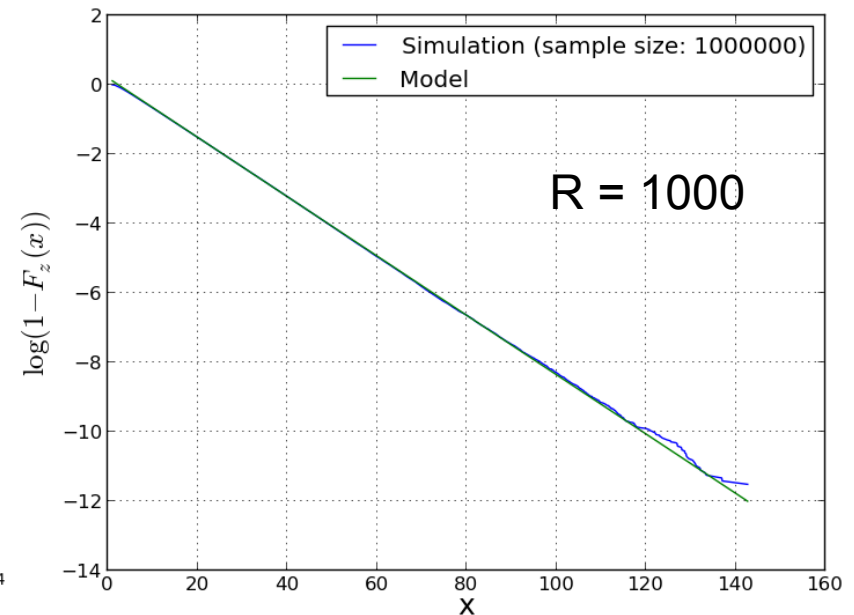
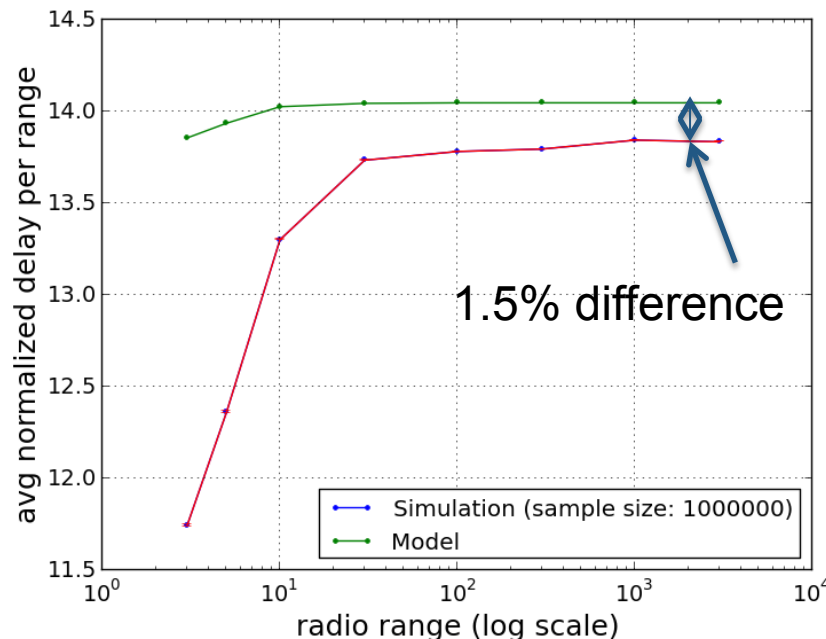
- Average delay: $E(\hat{Z}) = \frac{3\alpha\pi}{4} + \frac{3(\beta - \alpha)}{2n^2}$



Model and Approximation Validation

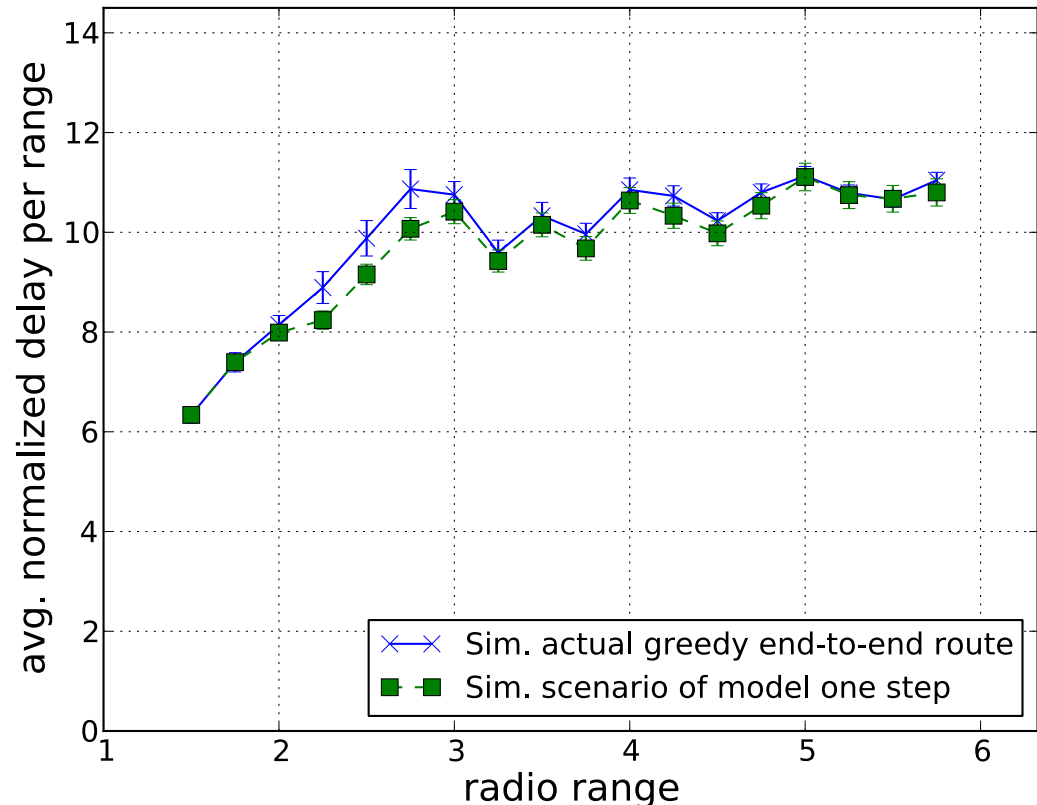
- Example of neighbors with random wake-up time
- Radio range $R = 3$ to 3000
- 1 million random draws -
- Good asymptotic fit - **Normalized delay estimate** $\frac{3}{2}\theta + \frac{3}{4}\pi$ **slots to travel by R**

$$\frac{3(N_c - 1)}{2n^2} + \frac{3\pi}{4}$$



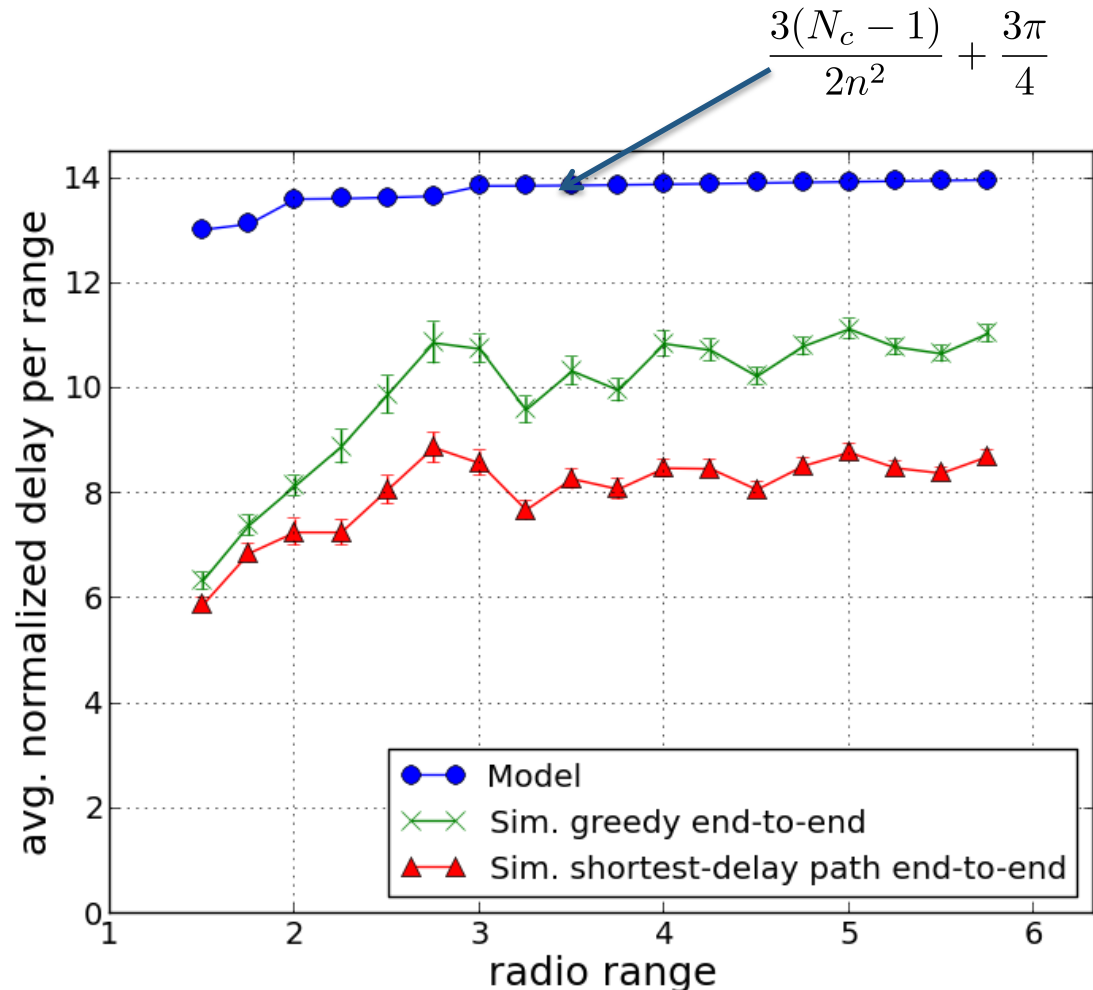
Simulation Results of IRCO

- Simulations: 100
- Area $L \times L$, with $L=601$
- Radio range: 1.5 to 6
- Sources:
100 random nodes
at distance $0.9 L$ to L
(annulus)
- STDMA: VCM with 3 hop
- Normalized delay per range
- Very close matching



Simulation Results of IRCO

- Simulations: 100
- Area $L \times L$, with $L=601$
- Radio range: 1.5 to 6
- Sources:
100 random nodes
at distance $0.9 L$ to L
(annulus)
- STDMA: VCM with 3 hop
- Normalized delay per range
- Close match

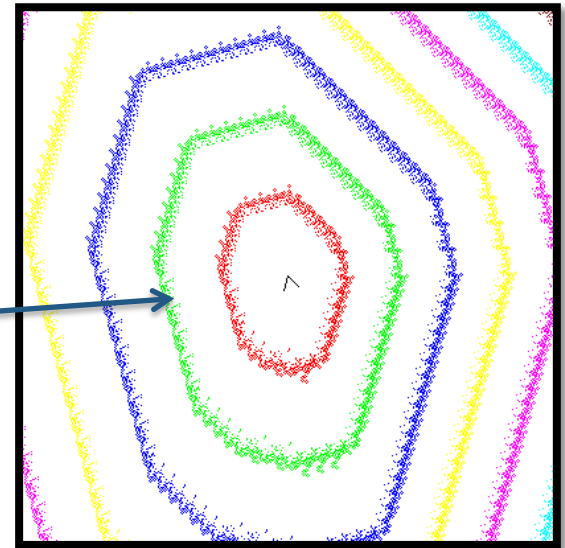


5

CONCLUSION

Conclusion and future work

- In a multi-hop wireless sensor network with STDMA
 - Analytic estimate of the delay with random ordering
 - Random ordering provides good performance
- Future work:
 - Explore limits/bounds of delays
 - Explore energy efficiency issues
 - Explain structure



Thank you

Questions?

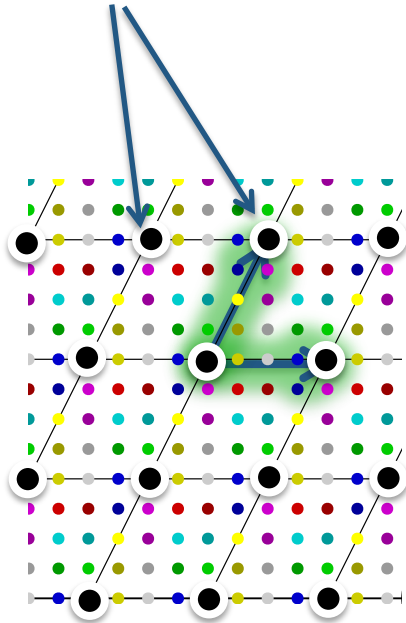
inria
informatiques mathématiques



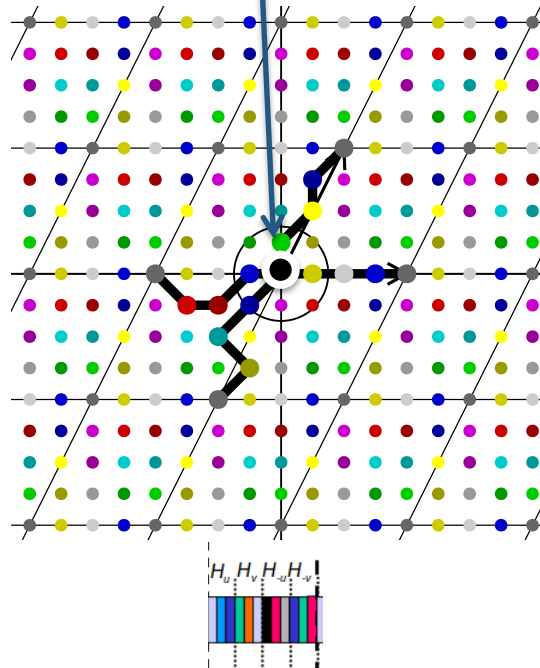
ORCHID: aggregators and highways

- Complex solution

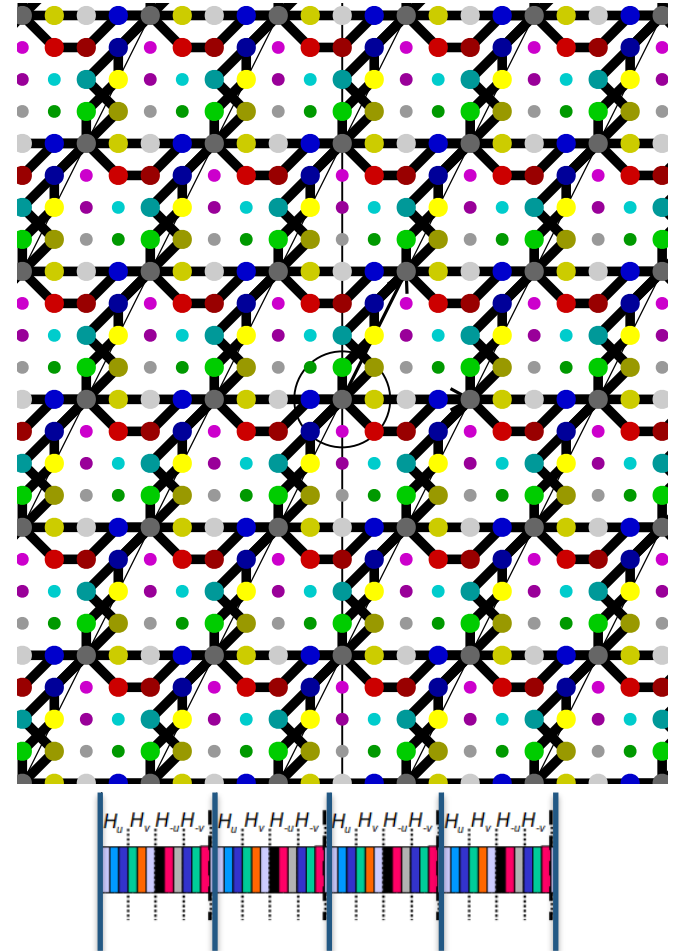
Aggregators



“c” (4)
at one aggregator

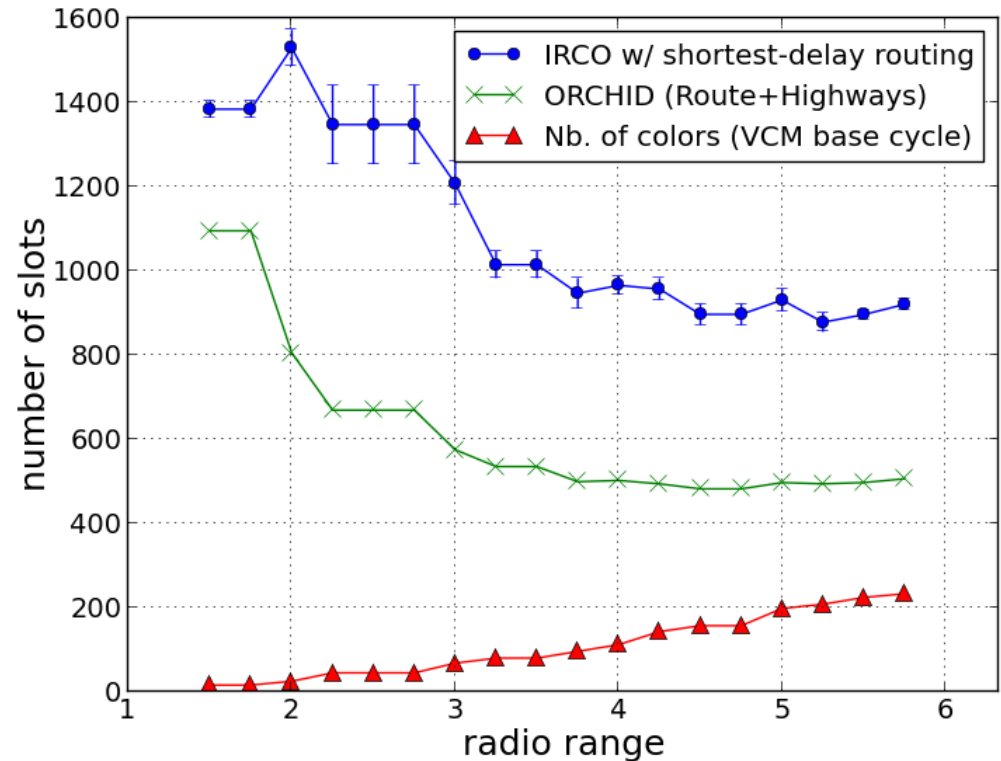


All aggregators and highways



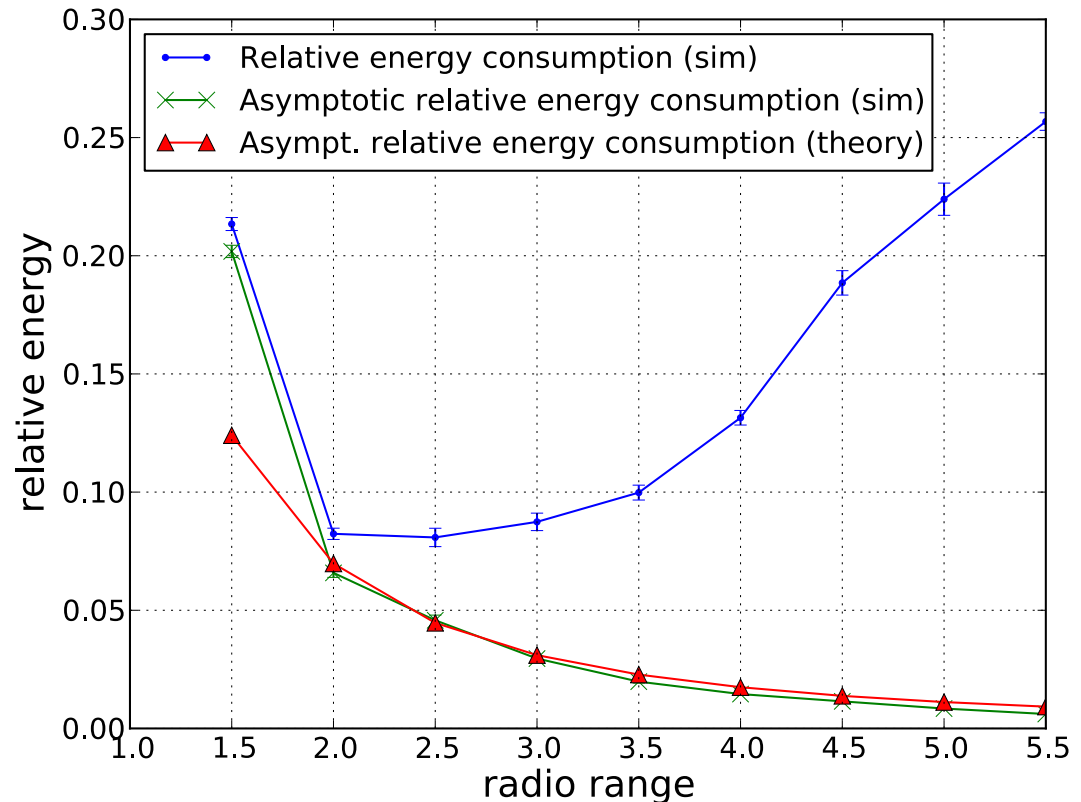
ORCHID cycle length

- Grid, range R
- VCM (3-hop coloring)
- Topology inside
 $L = 300$
- Nb. slots of cycle



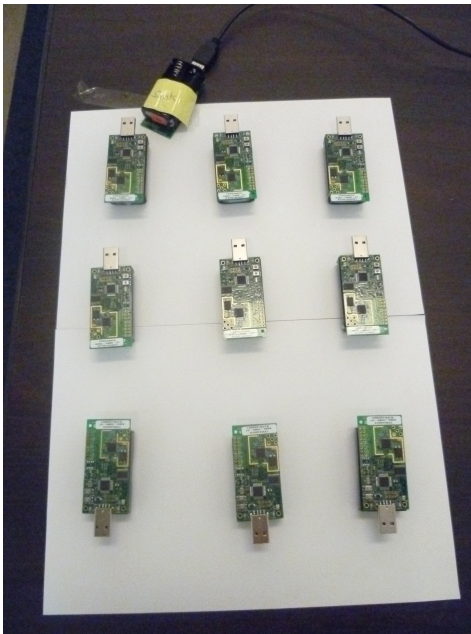
ORCHID Energy-Efficiency

- Energy:
sending/listening
- Asymptotic:
with size of network

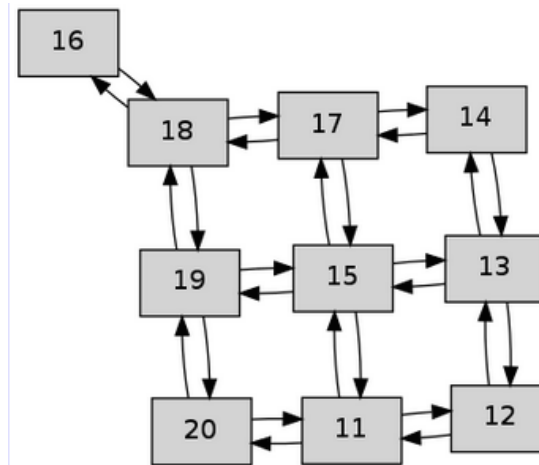


STDMA-based WSNs scheduling

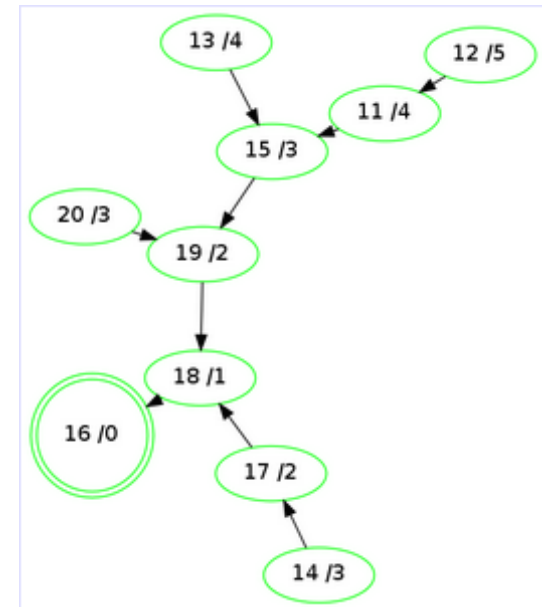
Example of protocol: OPERA (part of OCARI) <http://opera.gforge.inria.fr/>



Actual nodes



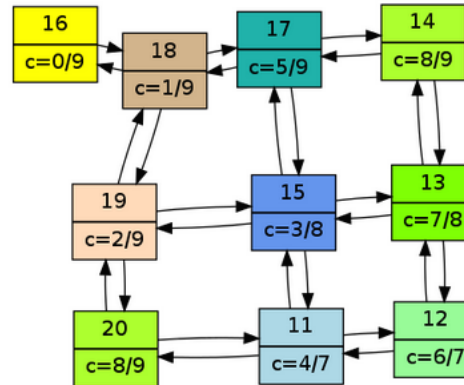
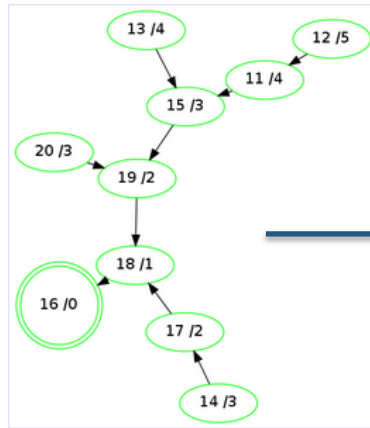
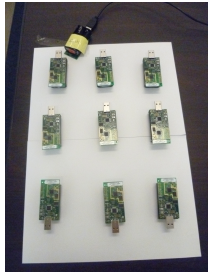
Topology
(neighborhood)



Routing tree to the sink

STDMA-based WSNs scheduling

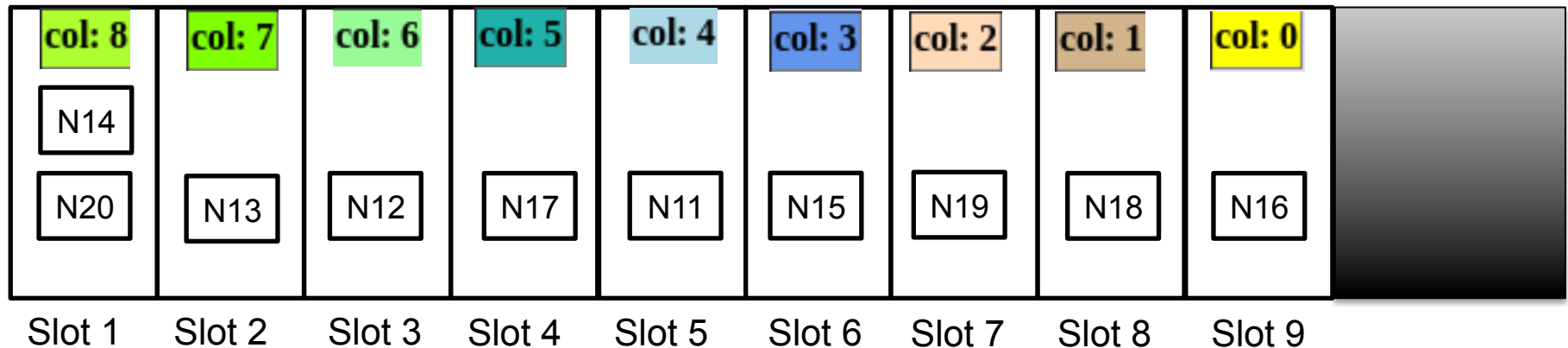
Example of protocol: OPERA (part of OCARI) <http://opera.gforge.inria.fr/>



Example “coloring” (OPERA):

- 3-hop coloring
- Ordering along routing tree

Schedule (cycle)



STDMA-based WSNs scheduling

Example of protocol: OPERA (part of OCARI) <http://opera.gforge.inria.fr/>

