Minimum Delay Data Gathering in Radio Networks

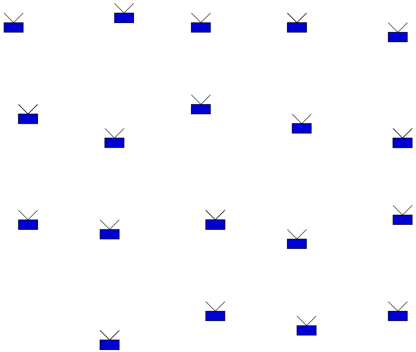
Jean-Claude Bermond, Nicolas Nisse, **Patricio Reyes**, Hervé Rivano

PROJET MASCOTTE - INRIA/I3S(CNRS-UNSA)

Algotel. June 17, 2009

Motivation

- Sensor Network



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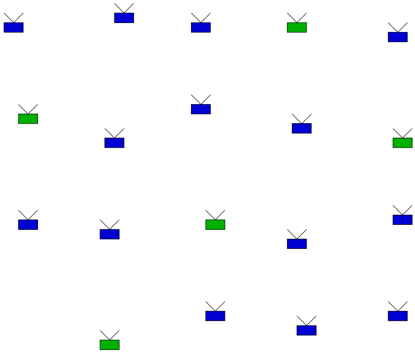

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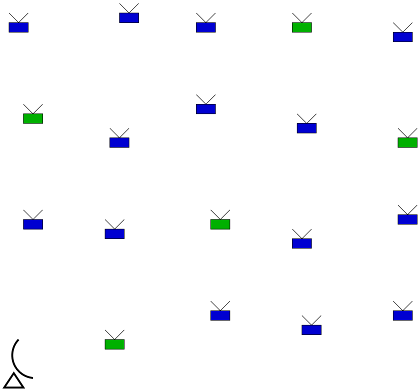

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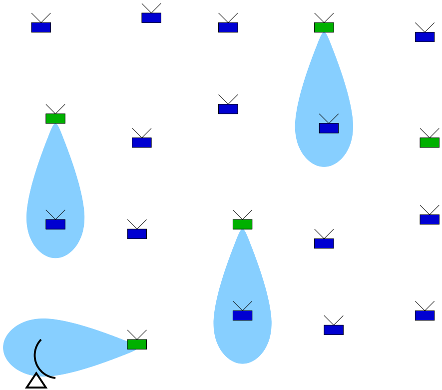

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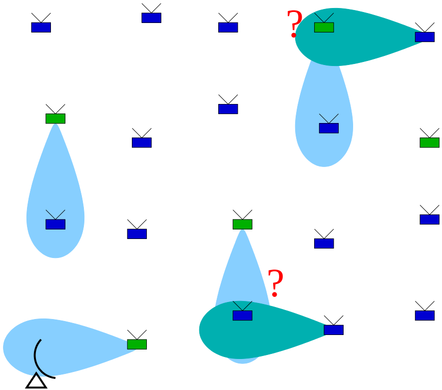


Gathering Problem

- The nodes have messages
- There is a special node called BS or gateway.
- Messages must be collected by the BS.
- Avoid interferences
- Time:
  - synchronous
  - discrete: time-slots $t = 1, 2, 3, \ldots$
- Goal: Minimize the gathering time $\rightarrow$ # time-slots

Transmission & Interference model

- Binary models
  - the sender sends a msg, then the recevier:
    1. receive the (entire) message
    2. no info is received
- Transmission distance
  - u is able to transmit to v if $d_G(u, v) \leq 1$
- Call $u \rightarrow v$
  - 1 time-slot
  - 1 message
- Round: set of non interfering calls $\leftrightarrow$ simultaneous calls
- Idea: *Good* rounds $\leftrightarrow$ time-slot

Motivation

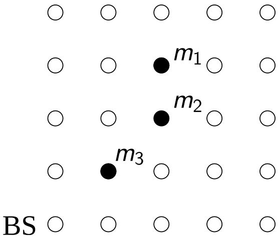
Revah and Segal'07

- Sensor Networks
- square grid with BS in $(0,0)$
- set of M messages
- Interference $\leftrightarrow$ matching
  Node cannot both receive and send at the same time-slot
  Node cannot receive more than one message at the same time-slot
- **new constraint: no-buffering** $\leftrightarrow$ hot-potato routing
  - node v receives a msg at time-slot t
    node v sends the msg at time-slot $t+1$

R&S Algo: *1.5-approximation

Gathering and Personalized Broadcasting

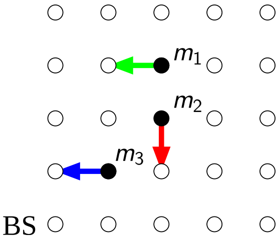
- Gathering



Gathering and Personalized Broadcasting

- Gathering

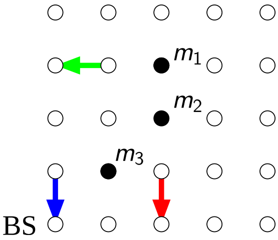
$t = 1$



Gathering and Personalized Broadcasting

- Gathering

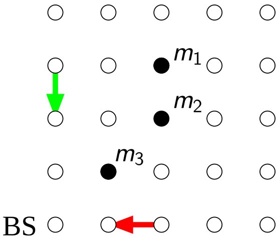
$t = 2$



Gathering and Personalized Broadcasting

- Gathering

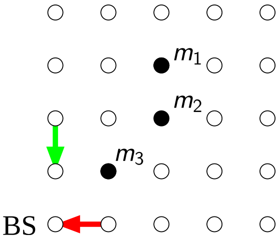
$t = 3$



Gathering and Personalized Broadcasting

- Gathering

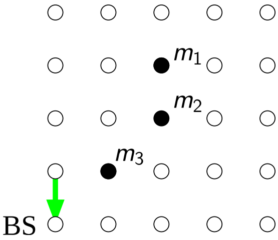
$t = 4$



Gathering and Personalized Broadcasting

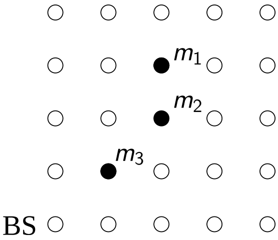
- Gathering

$t = 5$



Gathering and Personalized Broadcasting

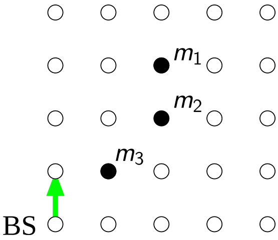
- Personalized Broadcasting



Gathering and Personalized Broadcasting

- Personalized Broadcasting

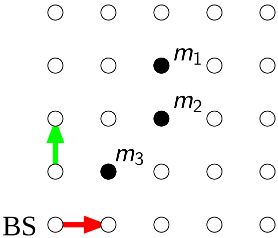
$t = 1$



Gathering and Personalized Broadcasting

- Personalized Broadcasting

$t = 2$



Gathering and Personalized Broadcasting

- Personalized Broadcasting

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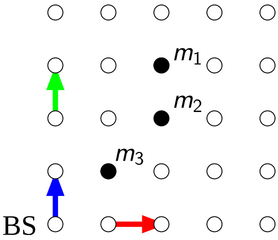
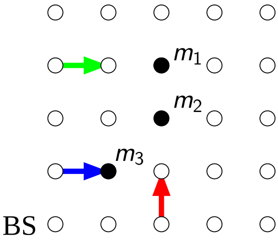


Gathering and Personalized Broadcasting

- Personalized Broadcasting

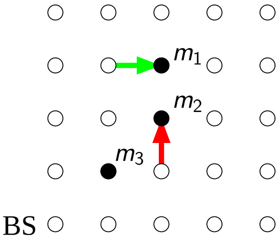
$t = 4$



Gathering and Personalized Broadcasting

- Personalized Broadcasting

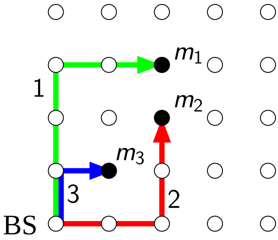
$t = 5$



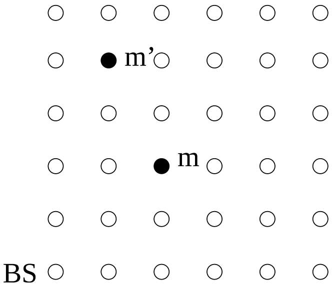
Gathering and Personalized Broadcasting

- Personalized Broadcasting

Sequence $\mathcal{S} = (m_1, m_2, m_3)$

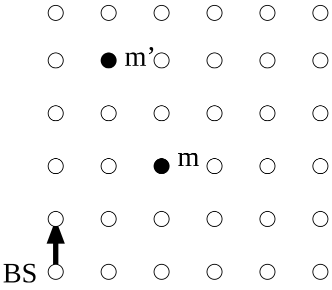


Interference



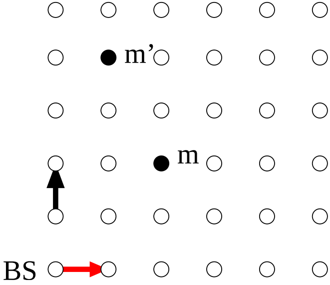
Interference

$t = 1$



Interference

$t = 2$



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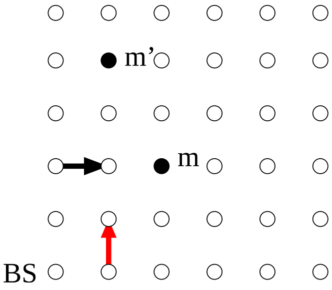
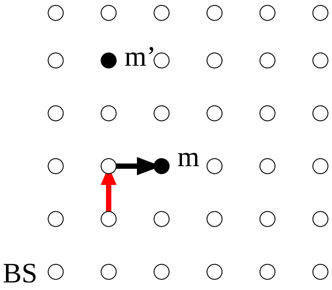


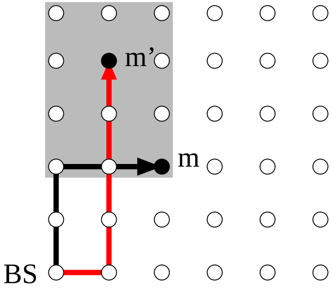
Interference

$t = 4$



Interference

Two consecutive msgs ↔ disjoints paths



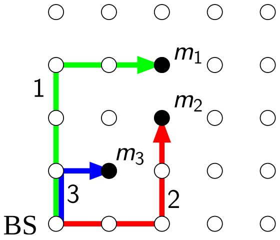
Methodology

- BS sends 1 msg per time-slot

t	1	2	3
	m_1	m_2	m_3

- Only HV and VH paths

t	1	2	3
	VH	HV	VH

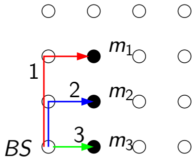


Methodology

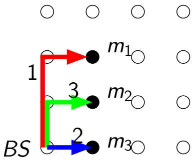
- gathering $\leftrightarrow$ personalized broadcasting
- BS sends 1 msg at each time-slot
- two consecutive msgs $\leftrightarrow$ disjoint paths
- $\mathcal{M} = \{m_1, \ldots, m_M\}$ such that $d(m_1) \geq d(m_2) \geq d(m_3) \geq \ldots \geq d(m_M)$, with $d(v) = d_G(dest(m_i), \mathrm{BS})$
- Goal: provide BS with a *good* delivery order $\mathcal{S} = (s_1, \ldots, s_M)$, $s_i \in \mathcal{M}, s_i \neq s_j$

Lower Bound

- without interferences
- order $(m_1, \ldots, m_M)$
- $LB = \max_{i \leq M} d(m_i) + i - 1$
- LB is not always optimal



$(m_1, m_2, m_3),\ LB = 3$



(m_1, m_3, m_2),
4 time-slots

Next results

Recall: $LB = \max_{i \leq M} d(m_i) + i - 1$
with $(m_1, \ldots, m_M)$

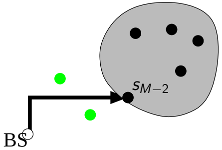
- $+2$-approximation algorithm
  - Protocol which attains the $LB + 2$
  - i-th msg (distance order) $\leftrightarrow$ time-slot $i \pm 2$
- $+1$-approximation algorithm
  - Protocol which attains the $LB + 1$
  - i-th msg (distance order) $\leftrightarrow$ time-slot $i \pm 1$

+2 Approx Algorithm

- Recall: $(m_1, \ldots, m_M)$ ordered by distance
- Induction including pair of nodes. $(m_1, m_2) \rightsquigarrow (s_1, s_2)$
- Sequence $(s_1, \ldots, s_{M-2})$, satisfying the following:
  - (i) it broadcasts the messages without interferences, sending (arbitrarily) the last msg vertically (VH)
  - (ii) $s_i \in \{m_{i-2}, m_{i-1}, m_i, m_{i+1}, m_{i+2}\}$, $i < M$ and $s_{M-2} \in \{m_{M-3}, m_{M-2}\}$

t	$\ldots$	i	$\ldots$	$M-2$
		m_{i-2}, m_{i-1}, m_i m_{i+1}, m_{i+2}		m_{M-3}, m_{M-2}

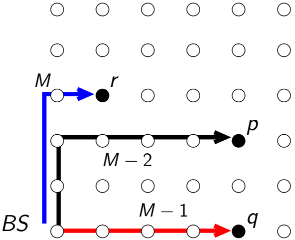
- Two new messages $\{m_{M-1}, m_M\}$ must be sent.



+2-approx algorithm

Notation: $q, r \in \{m_{M-1}, m_M\}$, q lower than r, and $p = s_{M-2}$

Case 1 q lower than p

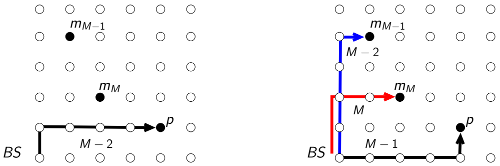


t ···	$M-2$	$M-1$	M
	$p \rightarrow m_{M-2}, m_{M-3}$	$q \rightarrow m_{M-1}/m_M$	$r \rightarrow m_M/m_{M-1}$

Properties (i) and (ii) !!

- Notation: $q, r \in \{m_{M-1}, m_M\}$, q lower than r, and $p = s_{M-2}$

Case 2 q higher than p

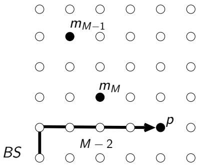


(a) before (b) after

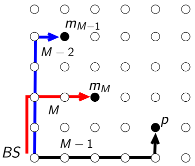
t ···	**M − 3**	$M-2$	$M-1$	M
	s_{M-3}	**p**	—	—
	s_{M-3}	m_{M-1}	**p**	m_M

- Notation: $q, r \in \{m_{M-1}, m_M\}$, q lower than r, and $p = s_{M-2}$

Case 2 q higher than p



(c) before



(d) after

t ···	**M − 3**	$M-2$	$M-1$	M
	m_{M-2}	$\mathbf{m_{M-3}}$	–	–
	m_{M-2}	m_{M-1}	$\mathbf{m_{M-3}}$	m_M

Properties (i) and (ii) !! $\leftrightarrow$ +2-approx

+1-approx Algorithm

(i) it broadcasts the messages without interferences, sending the last msg vertically

(iii) $s_i \in \{m_{i-1}, m_i, m_{i+1}\}$, $i < M$
and $s_M \in \{m_{M-1}, m_M\}$

t	$\cdots$	i	$\cdots$	$M-2$
		m_{i-1}, m_i, m_{i+1}		m_{M-3}, m_{M-2}

- Use +2-approx but fixing cases $s_i \in \{m_{i-2}, m_{i+2}\}$
  - +2-approx, except
  - special case: $s_{M-2} = m_{M-3}$

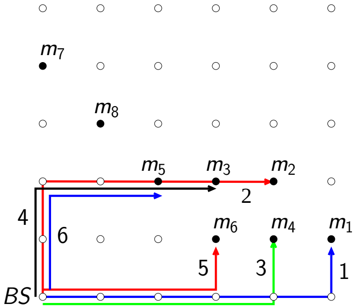


Figure: Before msgs m_7 and m_8

t	1	2	3	4	5	6	7	8
	m_1	$\mathbf{m_2}$	m_4	m_3	m_6	m_5	—	—

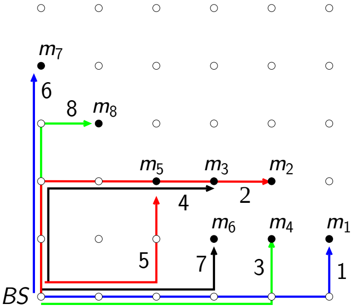


Figure: non valid sched, s_4, s_5 interfer

t	1	2	3	4	5	6	7	8
	m_1	$\mathbf{m_2}$	m_4	m_3	m_6	m_5	—	—
	m_1	$\mathbf{m_2}$	m_4	~~m_3~~	~~m_5~~	m_7	m_6	$\mathbf{m_8}$

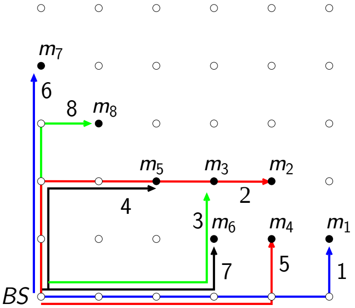


Figure: non valid sched, s_2, s_3 interfer

t	1	2	3	4	5	6	7	8
	m_1	$\mathbf{m_2}$	m_4	m_3	m_6	m_5	—	—
	m_1	$\mathbf{m_2}$	m_4	~~m_3~~	~~m_5~~	m_7	m_6	$\mathbf{m_8}$
	m_1	~~$\mathbf{m_2}$~~	~~m_3~~	m_5	m_4	m_7	m_6	$\mathbf{m_8}$

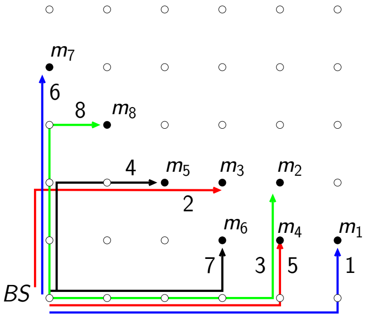


Figure: Final valid schedule

t	1	2	3	4	5	6	7	8
	m_1	$\mathbf{m_2}$	m_4	m_3	m_6	m_5	—	—
	m_1	$\mathbf{m_2}$	m_4	~~m_3~~	~~m_5~~	m_7	m_6	$\mathbf{m_8}$
	m_1	~~$\mathbf{m_2}$~~	~~m_3~~	m_5	m_4	m_7	m_6	$\mathbf{m_8}$
	m_1	m_3	m_2	m_5	m_4	m_7	m_6	$\mathbf{m_8}$

Properties (i) and (iii) !! $\leftrightarrow$ $+1$-approx

Complexity

M number of messages

$+2$ Approximation

- $O(M)$

$+1$ Approximation

- $O(M) \longleftarrow$ we don't have to change ALL the sequence

Conclusions

Results

- +2-approx
- distributed +2-approx
- +1-approx (Revah and Segal 07: *1.5-approx)
- no-buffering

Further work

- online version?
- different interference models

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Complexity

j						i	$i+2$					l	$l+2$
$\mathbf{m_j}$						m_{i-1}							
$\mathbf{m_j}$				×	×		$\mathbf{m_{i+2}}$						
$\mathbf{m_j}$			×	×			$\mathbf{m_{i+2}}$						
$\mathbf{m_j}$		×	×				$\mathbf{m_{i+2}}$						
$\mathbf{m_j}$	×	×					$\mathbf{m_{i+2}}$						
							$\mathbf{m_{i+2}}$		$\cdots$			m_{l-1}	$\mathbf{m_{l+2}}$
							$\mathbf{m_{i+2}}$			×	×		$\mathbf{m_{l+2}}$
							$\mathbf{m_{i+2}}$		×	×			$\mathbf{m_{l+2}}$
							$\mathbf{m_{i+2}}$	×	×				$\mathbf{m_{l+2}}$

- Time Complexity of $+1$-approx: $O(M)$