XOR Network Coding for Data Mule Delay Tolerant Networks

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Outline

Scenario descriptions

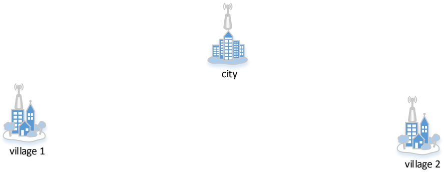

Fig. 1 : A village-to-village communication network

- No infrastructure between remote villages and the city

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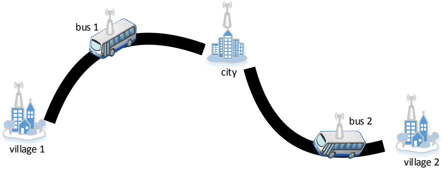

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- Communications rely on data mules: bus1, bus2
- Messages take time to arrive

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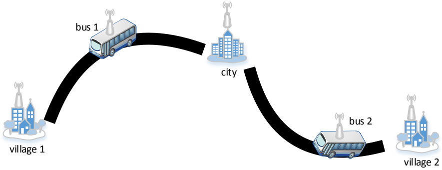

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- **Data mule delay tolerant networks**

Problem definition

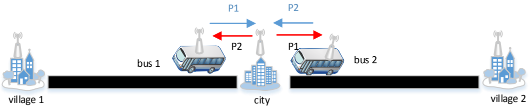
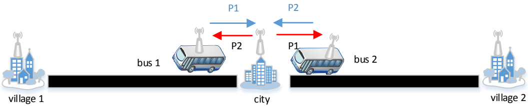


Fig. 2 : A village-to-village communication network

- The bandwidth is divided among contending nodes
- The fair media access control, such as CSMA, TDMA



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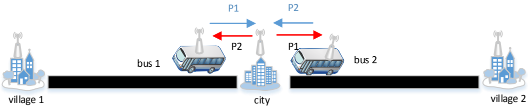

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- **XOR network coding**

XOR network coding benefits

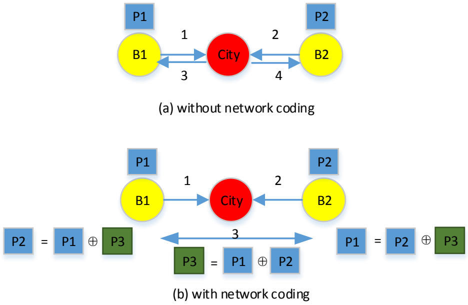

Fig. 3 : Inter-session XOR network coding benefit

Benefits:

- Save one transmission
- Balance the bandwidth between the city and the buses

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   - Scenario descriptions
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2. Theoretical analysis and simulation results
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   - Village-to-village of N_v villages
   - Village-to-village with different overlapping intervals
3. Extension to a real network

Modelling

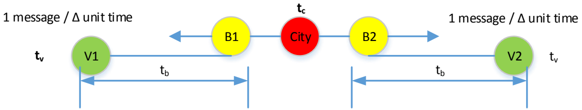

Fig. 4 : A basic village-to-village communication network model

Assumption:

- A homogeneous setting:
  - the same bus waiting time at villages (t_v) and the city (t_c)
  - the same travelling time for buses t_b
  - the same arrival and departure time of buses
- Each packet takes a unit time for transmission

Analysis (1/2)

The delivery probability gain

$$G_p = P_{nc} - P$$

where

- $P_{nc} = N_{nc}/(2 \cdot L)$, the delivery prob. *with* network coding
- $P = N/(2 \cdot L)$, the delivery prob. *without* network coding
- $L = T/\Delta$, number of messages carried by one bus
- $T = 2t_b + t_v + t_c$, round-trip time of a bus

Derive a mathematical relationship: $G_p = f(\Delta)$

- G_p the delivery probability gain
- Δ message creation period at villages

Analysis (2/2)

$G_p = f(\Delta)$

$$\begin{cases} G_p = \Delta \cdot \dfrac{t_c}{6 \cdot T}, & \Delta < 3 \cdot T/t_c \\ G_p = 2 - \dfrac{t_c}{2 \cdot T} \cdot \Delta, & \Delta \in [3 \cdot T/t_c, 4 \cdot T/t_c) \\ G_p = 0, & \Delta \geq 4 \cdot T/t_c \end{cases}$$

While $\Delta = 3 \cdot T/t_c$, G_p reaches the maximum, i.e., $1/2$

- The ONE (Opportunistic Network Environment) simulator
- Assign 100 to t_v, t_b, t_c

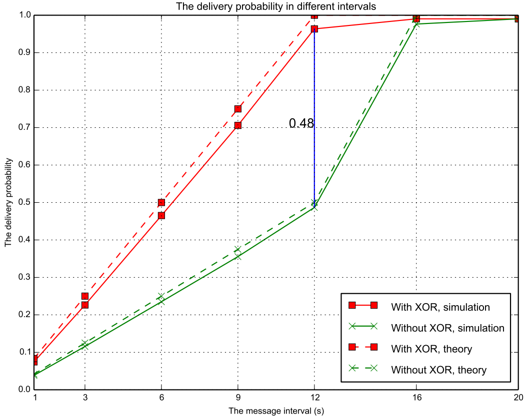

Fig. 5 : The delivery probability for the basic village-to-village scenario

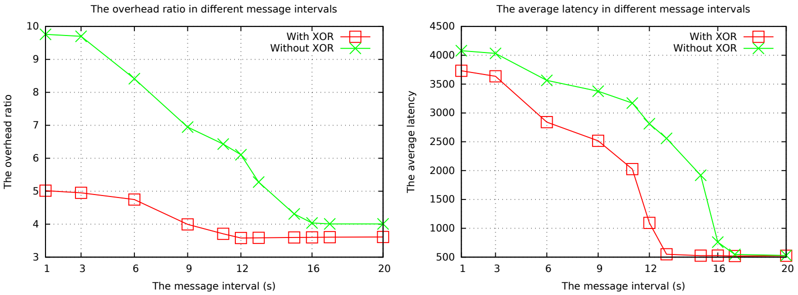

Fig. 6 : Overhead ratio (left) and average latency (right) for $N_v = 2$

The overhead ratio

The ratio of the number of transmissions to the number of messages delivered.

Outline

Village-to-village of N_v villages

- N_v: the number of villages
- $N_v/2$ pair-wise cross flows

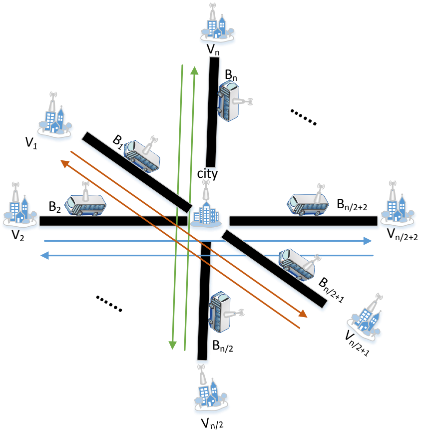

Fig. 7 : Village-to-village communication of N_v villages

Analysis

$G_p = f(N_v, \Delta)$

$$
\begin{cases}
G_p = \dfrac{t_c \cdot \Delta}{N_v \cdot (N_v+1) \cdot T}, & \Delta \le (N_v+1) \cdot T / t_c \\
G_p = \dfrac{t_c \cdot \Delta}{N_v \cdot T} - 1, & \Delta \in \left(\dfrac{(N_v+1) \cdot T}{t_c}, \dfrac{3 \cdot N_v \cdot T}{2 \cdot t_c} \right) \\
G_p = 2 - \dfrac{t_c \cdot \Delta}{T \cdot N_v}, & \Delta \in \left[\dfrac{3 \cdot N_v \cdot T}{2 \cdot t_c}, \dfrac{2 \cdot N_v \cdot T}{t_c} \right) \\
G_p = 0, & \Delta \ge \dfrac{2 \cdot N_v \cdot T}{t_c}
\end{cases}
$$

where

- G_p the delivery probability gain
- Δ the message creation period
- N_v the number of villages

- The maximum gain $G_p = 1/2$, while $\Delta = \frac{3 \cdot N_v \cdot T}{2 \cdot t_c}$

Simulation results of 4 villages

Assign 100 to t_v, t_b, t_c, 4 to N_v

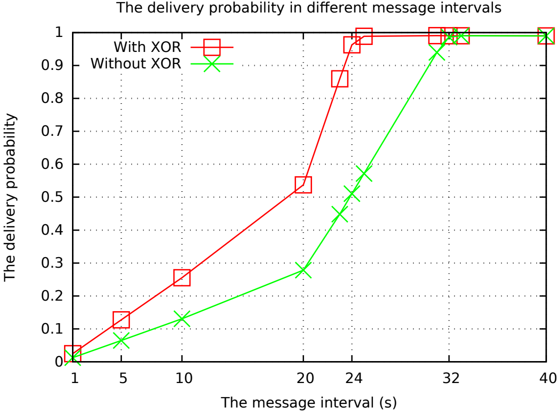

Fig. 8 : The delivery probability for 4 villages ($N_v = 4$)

Outline

Village-to-village with different overlapping intervals

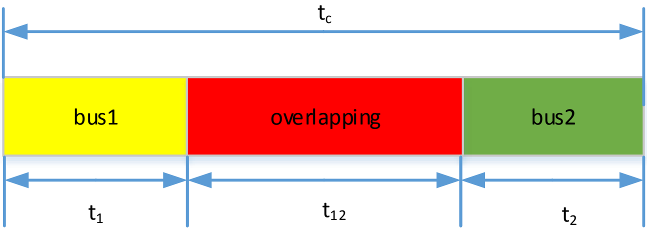

Fig. 9 : Overlapping intervals

With the assumption of $t_1 = t_2$, $G_p = f(t_{12})$

- $G_p = \frac{t_{12}}{6 \cdot T} \cdot \Delta$ (the base station cannot drain messages)

Assign 100 to t_v, t_b, t_c, 12 to Δ,

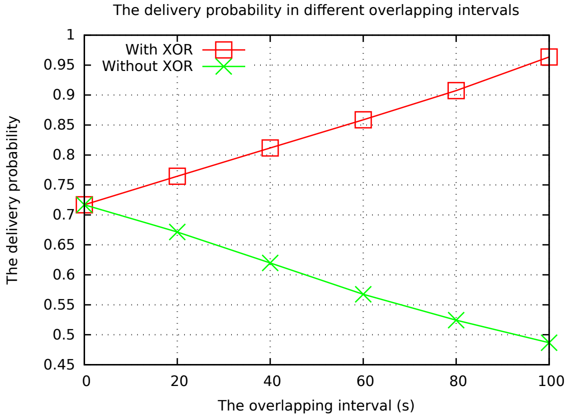

Fig. 10 : The delivery probability in different overlapping intervals ($N_v = 2$)

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Extension to a real networks (1/2)

- Tisséo Toulouse open data
- the overlapping time of pair of buses
- the amount of data that two buses can exchange one day

$$D = [min(t_1, t_2) + \frac{1}{3} \cdot t_{12}] \cdot R \quad (1)$$

$$D_{nc} = [min(t_1, t_2) + \frac{2}{3} \cdot t_{12}] \cdot R \quad (2)$$

The throughput gain

$$G_t = (D_{nc} - D)/D$$

where

- R, bit rate or transmission rate of base station
- D, amount of data exchanged *without* network coding
- D_{nc}, amount of data exchanged *with* network coding

Extension to a real networks (2/2)

Assign $R_b = 100Mb/s$,

Table 1 : The throughput improvements achieved by network coding

line1	line2	t_1	t_{12}	t_2	r(%)	D(GB)	D_{nc}(GB)	G_t(%)	station
10s	38s	0:00:00	1:15:00	0:56:00	57.25	18.75	37.5	100.00	Cours Dillon
2s	38s	0:00:00	1:04:00	1:07:00	48.85	16.0	32.0	100.00	Cours Dillon
2s	78s	0:17:00	0:34:00	0:00:00	66.67	8.5	17.0	100.00	Université Paul Sabatier
2s	81s	0:00:00	0:51:00	1:37:00	34.46	12.75	25.5	100.00	Université Paul Sabatier
78s	81s	0:00:00	0:34:00	1:54:00	22.97	8.5	17.0	100.00	Université Paul Sabatier
79s	81s	0:00:00	1:08:00	1:20:00	45.95	17.0	34.0	100.00	Université Paul Sabatier
T1	T2	12:37:00	6:04:00	0:00:00	32.47	91.0	182.0	100.00	Palais de Justice
10s	2s	0:12:00	1:03:00	0:01:00	82.89	16.5	32.25	95.45	Cours Dillon
2	VILLE	4:29:00	6:54:00	0:13:00	59.48	113.25	216.75	91.39	Cours Dillon
112	62	0:28:00	8:04:00	2:50:00	70.97	142.0	263.0	85.21	Ramonville
111	112	2:48:00	8:03:00	0:29:00	71.03	142.5	263.25	84.74	Ramonville
112	37	0:31:00	8:01:00	3:40:00	65.71	143.5	263.75	83.80	Ramonville
26	36	0:45:00	10:16:00	1:58:00	79.08	187.75	341.75	82.02	Borderouge
2	82	10:44:00	1:39:00	0:07:00	13.20	30.0	54.75	82.50	Université Paul Sabatier
202	62	1:22:00	11:03:00	0:50:00	83.40	203.25	369.0	81.55	Castanet-Tolosan
...	...	...	...	...	...	...	...	...	...
In total:		-	-	-	38.12	26891.75	41425.0	54.04	-

$r = t_{12}/(t_1 + t_{12} + t_2)$, ratio of overlapping intervals

Thanks for your attention.

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