Performance analysis and formal verification of cognitive wireless networks

Gian-Luca Dei Rossi   Lucia Gallina   Sabina Rossi

Dipartimento di Scienze Ambientali, Informatica e Statistica
Università Ca' Foscari, Venezia

EPEW 2013, Venice, 16-17 September 2013

Topology control

Possibly conflicting goals:

- Ensure network connectivity
- Optimise indices such as
    - throughput
    - response time
    - energy consumption
    - ...

Realised through protocols and other strategies of the nodes

Particularly useful in (mobile) wireless networks.

Cognitive Networks

Networks in which nodes are *smart*

- Stations can alter their behaviour
- Adaptation to environmental conditions Difference with *Cognitive Radio* networks
  - Not limited to channel selection
  - Decisions can be taken by complex algorithms

Here we consider the use of *cognitive networks* for topology control in a mobile wireless setting.

Problem setting

We consider a class of (wireless) cognitive networks in which

- nodes can move
- communications are point-to-point
- message are routed through the gossip protocol
- nodes can **dynamically tune** their transmission power *according to past observations*

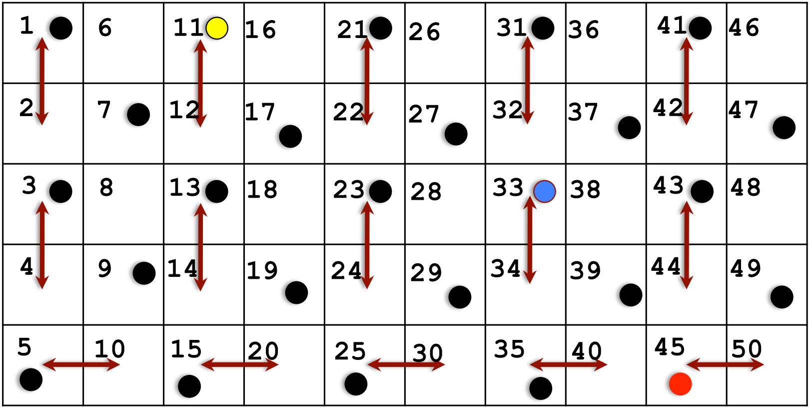
Power tuning strategy

- If there is $r < r_{\text{max}}$ for which there are at least n neighbour nodes, use the minimum transmission power capable of transmitting with radius r.
- Use the maximum allowed power, corresponding to r_{max}, otherwise.

Aim of the paper

- We propose a *formal probabilistic model* for that class of networks
- Locations and movement are discretised, transmissions are slotted
- Underlying stochastic process is a DTMC
- Encoded in order to use PRISM to do
  - Quantitative performance analysis
  - Probabilistic model checking
- Each node and its behaviour is represented by a PRISM language module

Network Topology



15 mobile, 10 static nodes. Area: 50x100 m. Grid cell: 10x10 m.

Node definition

module P8

$\texttt{steps8} : [0..2]\ \texttt{init}\ 2;$

$\texttt{l8} : [15..20]\ \texttt{init}\ 15;$

$[\texttt{move}]\ (\texttt{l8} = 15) \rightarrow 0.8 : (\texttt{l8}' = 20) + 0.8 : (\texttt{l8}' = 15);$

$[\texttt{movee}]\ (\texttt{l8} = 20) \rightarrow 0.8 : (\texttt{l8}' = 15) + 0.8 : (\texttt{l8}' = 20);$

$//\texttt{beginning of a new round}$

$[\texttt{round}]\ \texttt{no\_one\_sending} \rightarrow (\texttt{steps8}' = 2);$

$//\texttt{transmission}$

$//[\texttt{c8}]\ (\texttt{steps8} = 1) \rightarrow (\texttt{steps8}' = 0);$

$//\texttt{reception}$

$[\texttt{c3}]\ (\texttt{steps8} = 2) \&\ \texttt{s1p3}\ \&\ \texttt{s1p38} \rightarrow \texttt{psend} : (\texttt{steps8}' = 1) + (1 - \texttt{psend}) : (\texttt{steps8}' = 0);$

$[\texttt{c3}]\ (\texttt{steps8} = 2) \&\ \texttt{s2p3}\ \&\ \texttt{s2p38} \rightarrow \texttt{psend} : (\texttt{steps8}' = 1) + (1 - \texttt{psend}) : (\texttt{steps8}' = 0);$

$[\texttt{c3}]\ (\texttt{steps8} = 2) \&\ \texttt{s3p3}\ \&\ \texttt{s3p38} \rightarrow \texttt{psend} : (\texttt{steps8}' = 1) + (1 - \texttt{psend}) : (\texttt{steps8}' = 0);$

$[\texttt{c3}]\ (\texttt{steps8}! = 2)\ |!((\texttt{s1p3}\ \&\ \texttt{s1p38})\ |\ (\texttt{s2p3}\ \&\ \texttt{s2p38})\ |\ (\texttt{s3p3}\ \&\ \texttt{s3p38})) \rightarrow (\texttt{steps8}' = \texttt{steps8})$

...

endmodule

What we could ask?

We could use PRISM capabilities to do *probabilistic model checking* through *Monte Carlo simulations*.

Probability of successful reception

```
P=?[F goal]
```

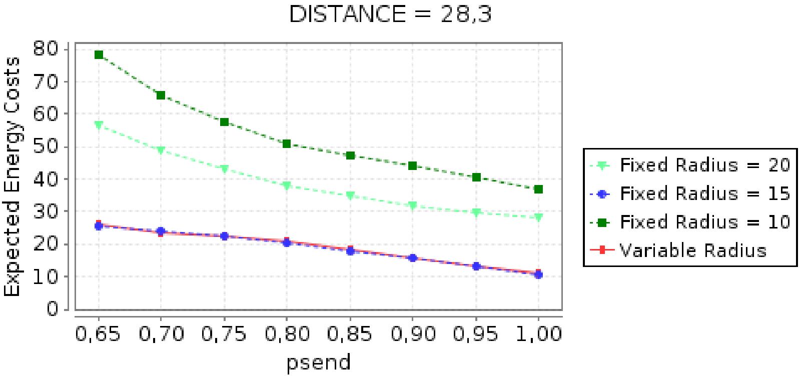
Energy cost of communication

```
R{"costs"}=?[F goal]
```

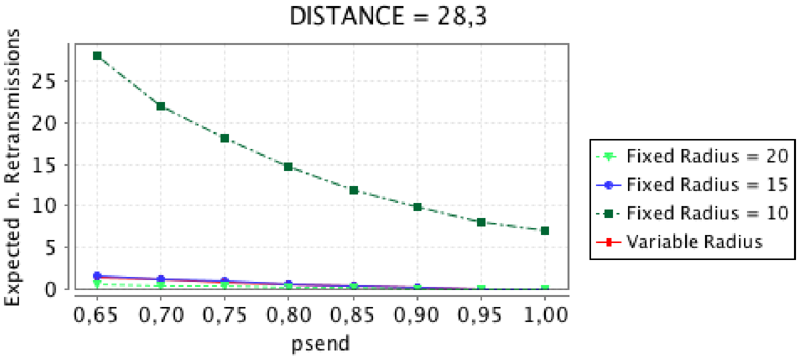
Expected Number of retransmissions

```
R{"rounds"}=?[F goal]
```

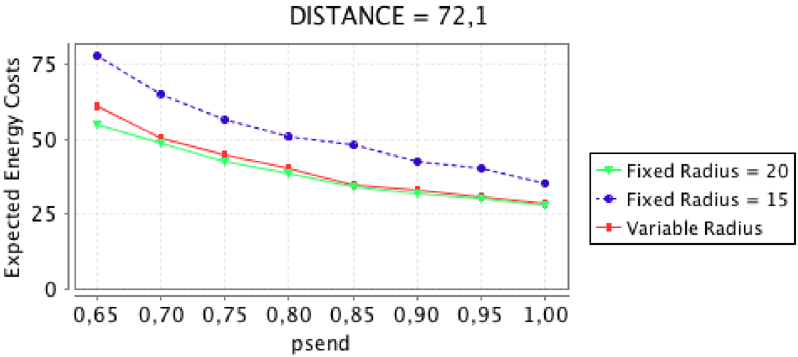
Example: Energy Cost



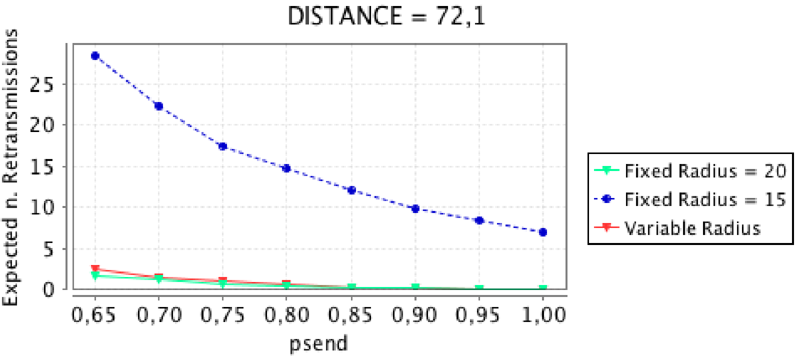
Example: Expected No. of Retransmissions



Example: Energy Cost



Example: Expected No. of Retransmissions



Numerical results

Table : Results for Energy Costs, Distance = 28,3 m

`VariableRadius`		`FixedRadius` = 15	
psend	**cost**	**psend**	**cost**
0.65	26.15733	0.65	25.5838
0.7	23.741	0.7	24.2405
0.75	22.5360	0.75	22.5333
0.8	20.7675	0.8	20.2982
0.85	18.2167	0.85	17.8995
0.9	15.7207	0.9	15.8523
0.95	13.3402	0.95	13.3570
1.0	11.21633	1.0	10.8015

Numerical results (2)

Table : Results for Energy Costs, Distance = 71,2 m

`VariableRadius`		`FixedRadius` = 20	
psend	**cost**	**psend**	**cost**
0.65	60.9090	0.65	54.7933
0.7	50.61383	0.7	48.95267
0.75	44.64067	0.75	42.7287
0.8	40.1177	0.8	38.3973
0.85	34.9950	0.85	34.2673
0.9	32.8725	0.9	32.1087
0.95	30.8292	0.95	30.2807
1.0	28.6423	1.0	28.1893

Conclusions

- We have proposed a probabilistic model for a class of cognitive networks
- Easy encoding in a formal specification language
- Performance Analysis and Model Checking

Possible future works include

- Looking for other performance indices and properties
- Further simplifications and/or generalisations
- Easier automatic generation of the model

Thanks!

Thank you for your attention

any question?