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Network Coding Protocols: Does Topology Matter?

Luísa Lima
Instituto de Telecomunicações
Departamento de Ciência de Computadores
Faculdade de Ciências da Universidade do Porto
luisalima@dcc.fc.up.pt

Diogo Ferreira
Instituto de Telecomunicações
Departamento de Ciência de Computadores
Faculdade de Ciências da Universidade do Porto
dferreira@dcc.fc.up.pt

João Barros
Instituto de Telecomunicações
Dep. De Eng. Electrotécnica e Computadores
Faculdade de Engenharia da Universidade do Porto
jbarros@fe.up.pt

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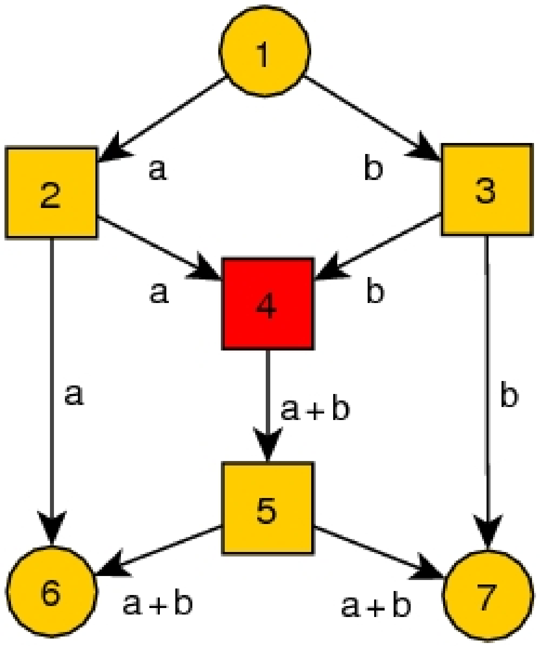
Motivation

- Network Coding is a technique for sending packets over a network
- Nowadays, network nodes simply store and forward data
- With Network Coding nodes combine input packets into one or more output packets



Motivation

- Fundamental impact of topology on the performance of network coding protocols is not yet understood
- Linear mixings performed by network coding protocols may have an impact on whether an intermediate node is able to recover any meaningful information

Main Goal

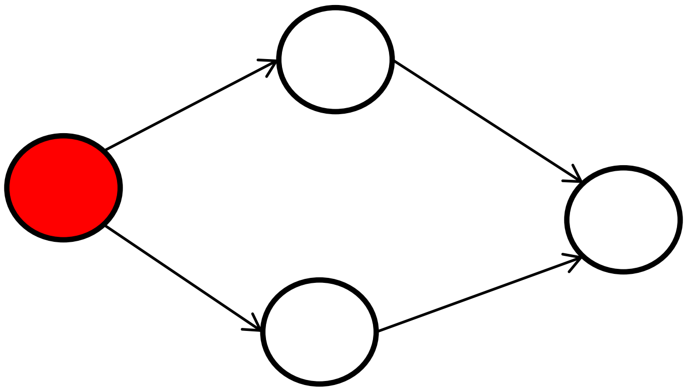
- Investigate the influence of topology on RLNC based protocols

Model

- Graph G = (V, E), V is the set of nodes and E is the set of edges, each with unit capacity
- One source and one sink randomly chosen
- Use the min-cut of the graph as generation size for the network coding protocol
- Same number of nodes for each graph, 100 nodes

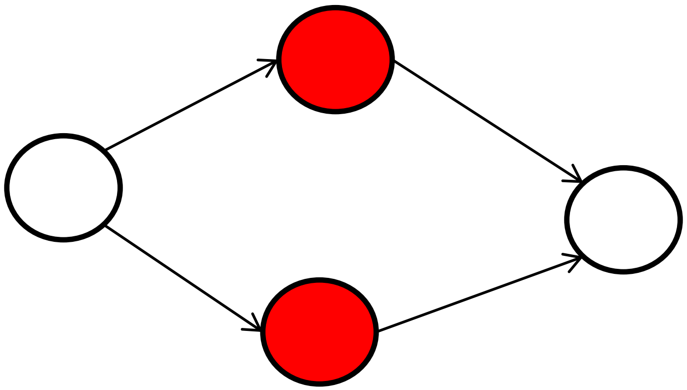
RLNC Protocol

- Source node:
  - Source forms the message packets $w_1,w_2,\ldots,w_h$ according to the same rules that the intermediate nodes use, where h corresponds to the min-cut of the network



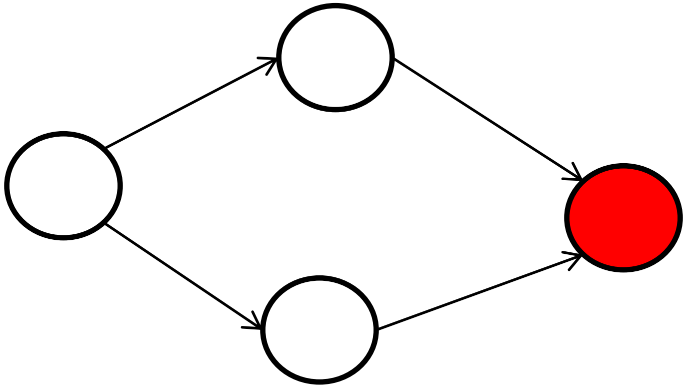
RLNC Protocol

- Intermediate node:
  - Gaussian elimination is performed with the packets already in the buffer
  - Node chooses all the packets $p_1, p_2, \ldots, p_L$ that are in his buffer
  - For all outgoing edges i:
    - Form packet: $x_i := \sum_{l=1}^{L} \alpha_l p_l$
    - where α_l is chosen according to a uniform distribution over the elements of the finite field $\mathbb{F}_q$



RLNC Protocol

- Sink node:
  - Gaussian elimination is performed with the packets already in the buffer
  - If inverse of the matrix M^l *exists*:
    - Node applies the inverse to the packets to obtain $w_1, w_2, \ldots, w_K$; otherwise, a decoding error occurs



Metrics

- *Throughput metric* – speed of dissemination of innovative information in the network
- *Cooperation opportunities in the network* – ability to obtain innovative information through the use of cooperation among the nodes
- *Security of the network* – suitability of the topology for secure network coding

Throughput metric

- Evaluation of the rank $R_v(t)$ and the number of effective symbols at node v, $E_v(t)$, both normalized by the global rank, G_R, sent

Cooperation opportunities in the network

- Determination of $R_{Sv}(t)$ and $E_{Sv}(t)$, where $S_v = \{v_i : (v, v_i) \in E)\}$, and $v, v_i\ \forall$i are intermediate nodes

Security of the network

- *Strong Algebraic Security* $\Delta_s(v)$ at an intermediate node *v*:
  - Minimum number of positions in the encoding matrix that node *v* needs to guess in order to decode one of the transmitted symbols, and is given by:

$$\Delta_s(v) = \frac{[G_R - 1 - (\max Z(l_i, \forall l_i \in M_v^R))]}{G_R}$$

- *Weak Algebraic Security* criterion $\delta_s(v)$ at an intermediate node *v*:
  - The number of symbols that *v* has to guess in order to decode all symbols, and is given by:

$$\delta_s(v,t) = \frac{G_R - L_R(v,t)}{G_R}$$

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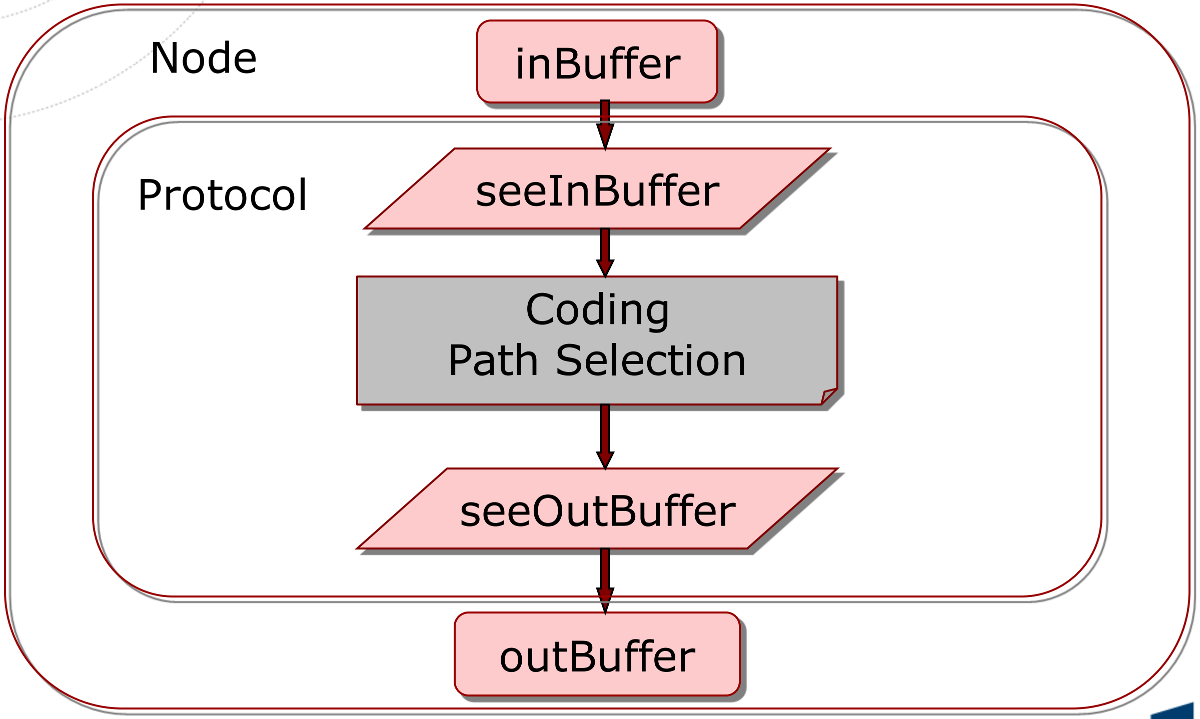
Simulations

- Study uses NECO version RC5 (Network Coding Simulator)
- Open-source simulator which allows for the evaluation of network coding protocols through simulation on complex networks



Simulations

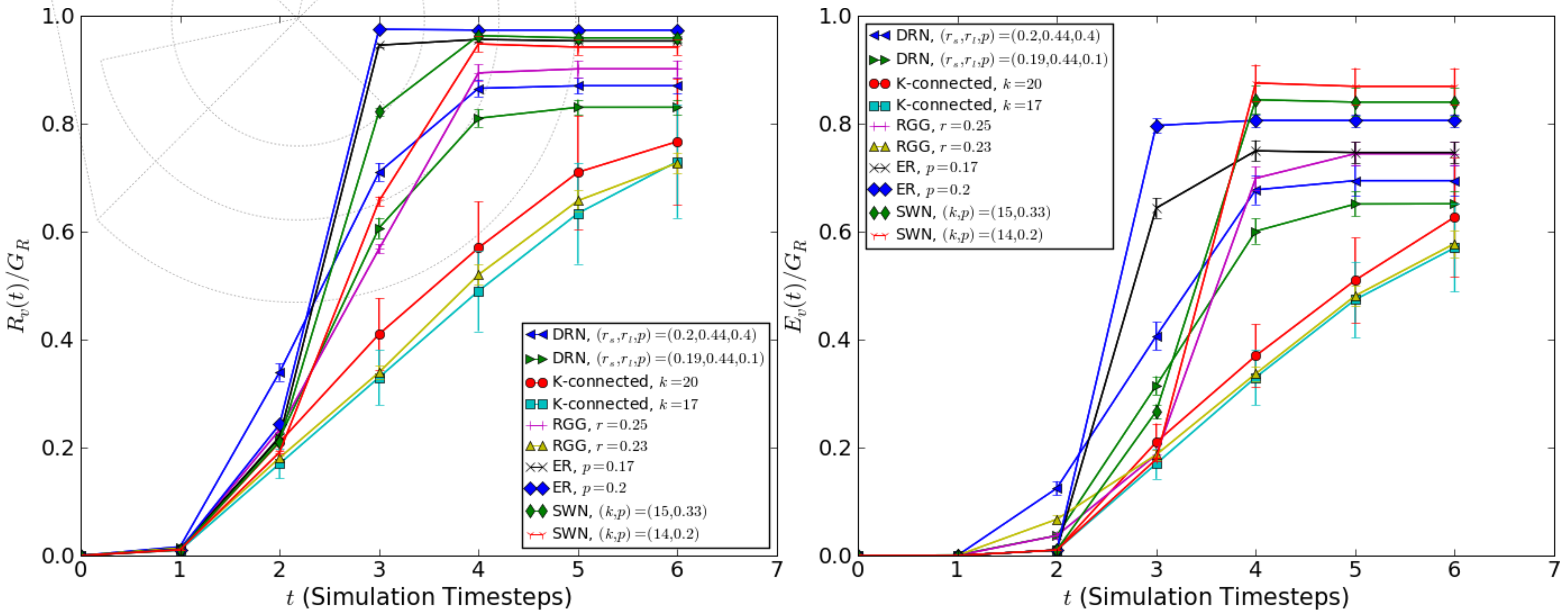
Algorithm 2 Simulation Methodology

for all random graph models **do**
  for all parameters $par \in parameter\_set$ **do**
    for i in **range**(0,20) **do**
      Generate random graph G with $seed_i$
      for j in **range**(0,10) **do**
        Select source s with $seed_j$ uniformly at random from V and sink t with $seed_j$ uniformly at random from $V \backslash \{s\}$
        Obtain min-cut $h = M_c(s,t)$ of G
        for l in **range**(0,5) **do**
          Run original RLNC algorithm with $seed_l$ and generation size h
          Stop when sink t has decoded.
        end for
      end for
    end for
  end for
end for

Evaluated graphs

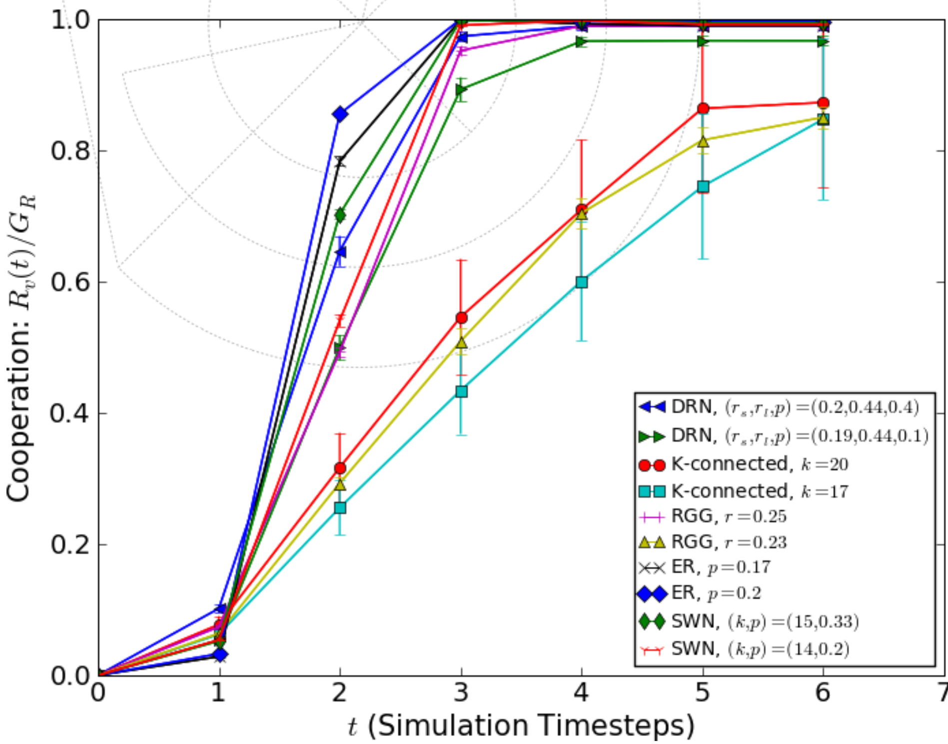
- *Érdös-Rényi – ER(n, p)*
- *Random Geometric Graph – RGG(n, r)*
- *Dual Radio Network – DRN(n, r_s, r_l, p)*
- *K-connected ring lattice – K-connected(n, k)*
- *Small-world Network with Shortcuts – SWN(n, k, p)*

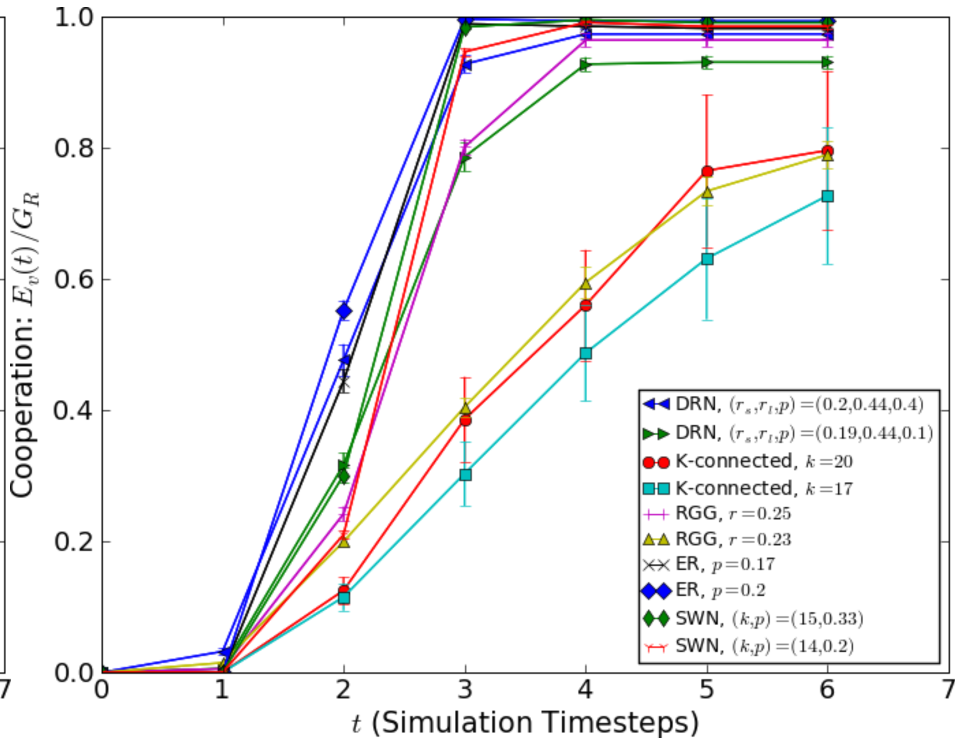
Results



Expected rank received and number of effective symbols, on the top and bottom

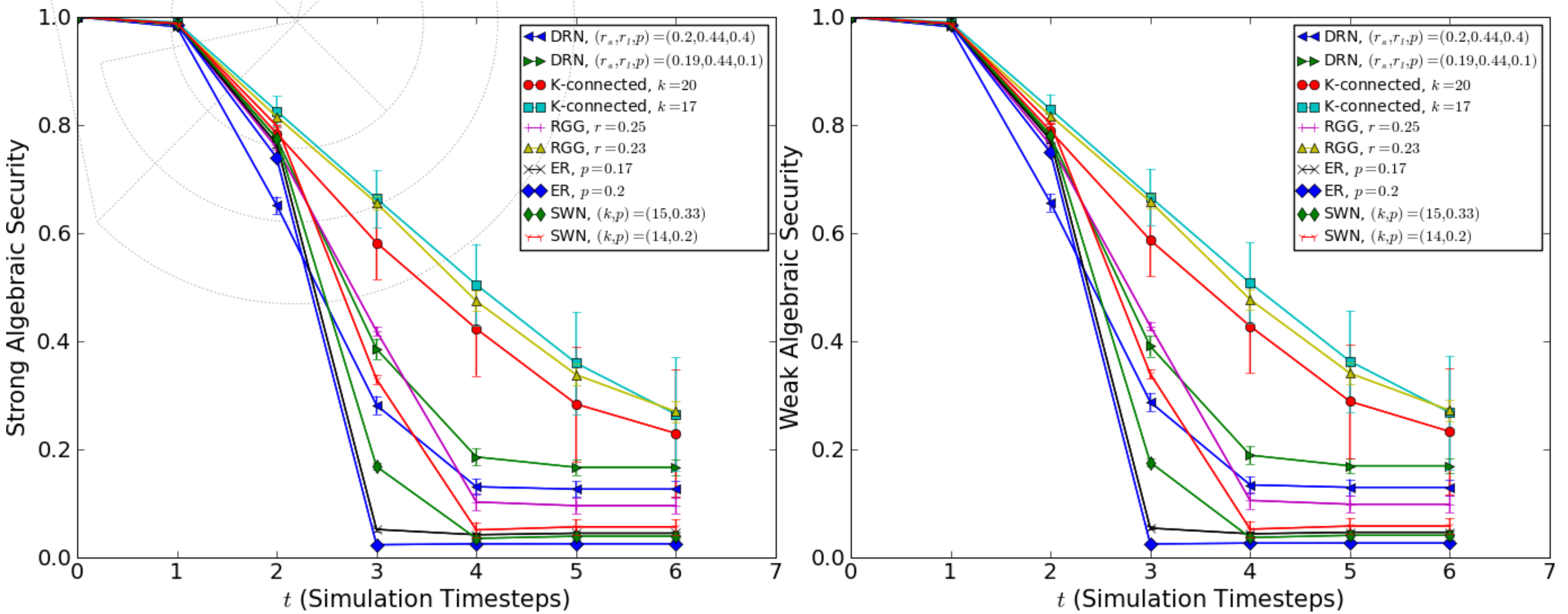
Results





Expected rank received and number of effective symbols, both achieved through cooperation with immediate neighbors

Results



Expected strong and weak algebraic security

Conclusion

- We evaluated the behaviour of RLNC by using various random graph models and a specific set of metrics
- Results show that typical wireless topologies are less prone to fast dissemination of information than the other classes topologies under consideration
- Future work:
  - Evaluation of the impact of mobility and dynamic links in the proposed RLNC based protocols in wireless networks
  - Use the insights from these abstract topology models to design and implement real-world network coding protocols