A Cross-Layer Design Based on Geographic Information for Cooperative Wireless Networks

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Context: Ad hoc

- Routing is challenging
- Multi-hop principle
- Geographic Routing

=> Attractive solution
  - Local, scalable, **but**

- Periodically use of beacons
- Inaccurate positions due to nodes mobility
- No a priori knowledge of Physical layer
  - Fading, interferences, instability
A Cross-layer approach is mandatory
- Information exchange between layers
- Make efficient routing decisions

Goal: fill the gap between geographic routing & channel conditions

How?
- Beaconless Geographic Routing
- Cooperative Communications

Reliable communication in terms of end to end delivery
Outline

Network model and problem statement

CoopGeo: cross-layer framework
  • Contention-based forwarder selection
  • Contention-based relay selection

Performance evaluation

Conclusions
Cooperative transmission (2-phase DF strategy with single-relay selection)

Two phases:
(1) $s$ broadcast its symbol to $r$ & $d$

$$y_{S,D} = \sqrt{P_x h_{S,D}} x + n_{S,D}$$

$$y_{S,R_i} = \sqrt{P_x h_{S,R_i}} x + n_{S,R_i}$$

(2) if $R_i$ correctly decodes, it forwards the symbol to $d$; otherwise, it remains idle

$$y_{R_i,D} = \sqrt{P_x I_{R_i}} h_{R_i,D} x + n_{R_i,D}$$

$$I_{R_i} = \begin{cases} 
 1, & \text{if } R_i \text{ decodes the transmitted symbol correctly} \\
 0, & \text{otherwise}.
\end{cases}$$

MRC: $$y_D = \sqrt{P_x h_{S,D}^*} y_{S,D} + \sqrt{P_x I_{R_i}} h_{R_i,D}^* y_{R_i,D}$$

Wireless channel = broadcast channel
Uncorrelated paths between nodes
No additional hardware needed
Consider a wireless network consisting of $K$ finite nodes, $V = \{v_1, v_2, \ldots, v_K\}$

- Multi-hop transmission is realized by concatenating direct or cooperative schemes
- A 2-phase DF strategy with single-relay selection is used in case of cooperation
Network model and problem statement

**Given** \( v_S, v_D \in V \ (v_S \neq v_D) \)

- Find a subset of forwarding nodes \( F = \{v_{f_1}, v_{f_2}, \ldots, v_{f_n}\} \subseteq V \) to guarantee a successful packet delivery from \( v_S \) to \( v_D \)
  
  => Forwarder selection

- Find an optimal subset of relay nodes \( R = \{v_{r_1}, v_{r_2}, \ldots, v_{r_{n+1}}\} \subseteq V \setminus F \) to enhance the network reliability
  
  => Relay selection
CoopGeo: Geographic contention based forwarding and cooperative communications

- Design a joint MAC/routing protocol for forwarder selection
  - Beaconless Geographic Routing
  => Geographic contention-based routing protocol

- Design a joint MAC/PHY protocol for relay selection
  - Cooperative Communications
  => Geographic contention-based relay-selection protocol
CoopGeo:

- No RTS/CTS mechanism
- Send the data
- Neighbors trigger a CBF process
  - If F is found and the packet can be decoded -> direct communication. Otherwise, ask for cooperation
  - CTF message
- S sends a confirm message ‘Sel’ to F
- If cooperation is needed, neighbors perform CBR process where the selected R relays the data to F
- F restarts forwarding
Geographic contention-based forwarder selection

- Define a CBF timer, $T_{CBF}$, for each candidate forwarder such that the optimal forwarder can win the competition and reply the CTF message most rapidly.


Geographic contention-based forwarder selection

- Divide the source’s coverage area into a PPA and a NPA
- Both areas are subdivided into several subareas
- Each candidate finds out which CSA it belongs to

\[
CSA_{PPA} = \left[ NSA \times \frac{r - (d_{S,D} - d_{F_i,D})}{2r} \right]
\]

\[
CSA_{NPA} = \left[ \left( \frac{\sqrt{n} \cdot d_{v,u}}{r(u)} \right)^2 + \frac{NSA}{2} \right]
\]

- Each candidate determines its CBF timer

\[
T_{CBF} = CSA \times \frac{T_{\text{max}}}{NSA} + \text{rand} \left( \frac{T_{\text{max}}}{NSA} \right)
\]

\[CSA \in \{0, 1, \ldots, NSA - 1\}\]
Define a CBR timer, $T_{CBR}$, for each candidate relay such that the optimal relay can win the competition and relay the message most rapidly.

Geographic contention-based relay selection

- Start with the proposed selection metric:
  \[ m_i = A^2 d_{S,R_i}^p + B d_{R_i,D}^p, \quad i = 1, 2, \ldots, N \]

- Solve the best-relay deployment problem:
  \[
  \text{minimize} \quad f(x) = A^2 \| x - x_S \|^p + B \| x - x_D \|^p
  
  \]

- As \( p = 2 \),
  \[ x^* = \frac{A^2 x_S + B x_D}{A^2 + B} \]

- Derive a mapping function \( M \) scaling the metric function into \([0, 1]\)

- Each candidate determines its CBR timer:
  \[
  T_{CBR} = T_{\text{max}} \times M(f(x)) + \text{rand} \left( \frac{2T_{\text{max}}}{NSA} \right)
  \]
Geographic contention-based relay selection

- Relay Area

1. Source transmission (data)
2. Forwarding contention
3. Select
4. Relay contention & transmission
## Parameters

<table>
<thead>
<tr>
<th>Input</th>
<th>Value</th>
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<th>Value</th>
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<tbody>
<tr>
<td>Num. of neighbors</td>
<td>1-20</td>
<td>Tx. Power</td>
<td>25 dBm</td>
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<td>Channel model</td>
<td>Rayleigh</td>
<td>Average Noise</td>
<td>20 dB</td>
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<tr>
<td>Carrier Frequency</td>
<td>2.412 Ghz</td>
<td>Noise Figure</td>
<td>15 dB</td>
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<td>Channel Bandwidth</td>
<td>22 Mhz</td>
<td>Packet Size</td>
<td>1538 Octets</td>
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<td>Modulation Type</td>
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<td>Num. Topologies</td>
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<tr>
<td>Constellation Size</td>
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<td>Simulations Run</td>
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<tr>
<td>Contention Period</td>
<td>500 us</td>
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Packet Error Rate

Transmission Error Probability

![Graph showing error transmission probability vs number of neighbors. The graph compares Direct and Cooperative methods.](graph.png)
Conclusions & further works

■ **CoopGeo**, based on geographic information to effectively integrate the network/MAC/physical layers for cooperative wireless networks.

■ The proposed **CoopGeo** provides a joint MAC/routing protocol for forwarder selection as well as a joint MAC/physical protocol for relay selection.
  - Forwarding selection in mobile networks
  - Relay selection without CSI information

■ **What is next?**
  - Integrate this cross-layer framework with the low power listening techniques for Wireless Sensor Networks
  - Testbed
Questions...

Thank you