Resource Reuse in Realistic Urban Networks

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4 December 2007
Motivation

Problems in Urban Networks:

- High user density
- Large traffic demand
- Congested Network
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Urban Environment:
- There is structure in the cell
- Dictated by urban design
- Users and calls naturally cluster together
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Our Solution
Utilize geography and the wireless environment to our advantage!
Our Contributions

- New view of the network topology
Our Contributions

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- Proposals for resource reuse
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- Mathematical formulation of the topology
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- Algorithm taking advantage of the environment
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- Algorithm taking advantage of the environment
- Simulation Results
Clustering

Users are often “clustered” together, in dense but geographically separated areas, within the same cell:
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Assumptions

System

- System uses TDD-TDMA: only timeslots are scheduled
- Base Station is aware of clustering
- Pathloss-only environment

Distributions
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Distributions

Users: Location
- Clusters: Uniform
- Users in Clusters: Gaussian
- General users: Uniform
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- System uses TDD-TDMA: only timeslots are scheduled
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Distributions

Users: Location
- Clusters: Uniform
- Users in Clusters: Gaussian
- General users: Uniform

Users: Calls
- Some “external” BS calls
- Some calls within the cluster
- Some likelihood of no calls
Proposal 1: Direct Communications

Allow nearby mobiles to use a much lower power level and communicate directly, without the base station.
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Proposal 2: Simultaneous Communications

Allow several local communications to occur at the same time, if they don’t interfere with each other. Same resource (time) is shared.
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\[
\begin{align*}
&n = 1 & n = 2 & n = 3 \\
UL & m_1 \rightarrow m_2 & m_3 \rightarrow m_4 & \\
DL & m_2 \rightarrow m_1 & m_4 \rightarrow m_3 & \ldots
\end{align*}
\]
How can several terminals communicate together?

Minimum SINR

If the SINR at each terminal is above a minimum value $\beta$, then nodes can communicate simultaneously.
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**Minimum SINR**

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The SINR in our case is dictated entirely by the pathloss value $\alpha$ and distance $d$. For link $i$:

$$\text{SINR}_i = \frac{P_{\text{LOC}} d_i^{\alpha}}{I + N}$$
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The SINR in our case is dictated entirely by the pathloss value $\alpha$ and distance $d$. For link $i$:

$$\text{SINR}_i = \frac{P_{\text{LOC}}}{d_i^{\alpha} I_i + N}$$

where the sum interference is written as

$$I_i = \sum_{j \neq i}^{L} \frac{P_{\text{LOC}}}{d_{ij}^{\alpha}}$$
Exploiting Geography
Preserving the Minimum SINR

Idea

If several *pairs* of nodes (links) are sufficiently separated in distance, then they will have little effect on each other’s SINR.

Identify locals calls in clusters far enough apart, and schedule them together to use the same resource.
Exploiting Geography
Preserving the Minimum SINR

Idea

If several *pairs* of nodes (links) are sufficiently separated in distance, then they will have little effect on each other’s SINR.

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Minimum Distance

\[
d_{\text{min}} = d_i^{\frac{\alpha}{\alpha+1}} (6r/\beta)^{\frac{1}{\alpha+1}}
\]
How can we use $d_{\text{min}}$?

**Partition Cluster Set**

Guarantee that clusters are at least $d_{\text{min}}$ apart, then schedule local calls in each cluster for simultaneous communication.
Example of Reuse Algorithm
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UL
\[ m_1 \rightarrow m_2 \]
\[ m_3 \rightarrow m_4 \]

DL
\[ m_1 \rightarrow m_2 \]
\[ m_3 \rightarrow m_4 \]
Example of Reuse Algorithm

UL

\[ m_1 \rightarrow m_2 \]
\[ m_3 \rightarrow m_4 \]
\[ m_5 \rightarrow m_6 \]
\[ \ldots \]

DL

\[ m_1 \rightarrow m_2 \]
\[ m_3 \rightarrow m_4 \]
\[ m_6 \rightarrow m_5 \]
\[ \ldots \]
Example of Reuse Algorithm

UL

\[ m_1 \rightarrow m_2 \]
\[ m_3 \rightarrow m_4 \]
\[ m_5 \rightarrow m_6 \]
\[ m_7 \rightarrow \text{BS} \]
\[ \ldots \]

DL

\[ m_1 \rightarrow m_2 \]
\[ m_3 \rightarrow m_4 \]
\[ m_6 \rightarrow m_5 \]
\[ \text{BS} \rightarrow m_7 \]
\[ \ldots \]
Theoretical Gains

Total Timeslots Used

Normal Scheme:
\[ N_C N_{cu} p_l + N_C N_{cu} p_{BS} + N_g p_{BS} \]

Algorithm:
Theoretical Gains
Total Timeslots Used

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Algorithm:
\[ \frac{N_C}{|C|} \frac{N_{cu} p_l}{2} + N_C N_{cu} p_{BS} + N_g p_{BS} \]
Theoretical Gains

Total Timeslots Used

Normal Scheme:
\[ N_C N_{cu} p_l + N_C N_{cu} p_{BS} + N_g p_{BS} \]

Algorithm:
\[ \frac{N_C N_{cu} p_l}{|C|} \frac{1}{2} + N_C N_{cu} p_{BS} + N_g p_{BS} \]

1. Direct Communication
Theoretical Gains

Total Timeslots Used

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1. Direct Communication
2. Resource Reuse
Theoretical Gains

Total Timeslots Used

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Algorithm:
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1. Direct Communication
2. Resource Reuse

Savings

\[ TS_{sav} = N_C N_{cu}p_l \left( 1 - \frac{1}{2|C|} \right) \]
Theoretical Gains

\[ TS_{\text{sav}} = N_C N_{\text{cu}} p_l \left( 1 - \frac{1}{2 |C|} \right) \]
User Density

- $p_{loc} = 0.3$, $p_{ext} = 0.3$, $p_{nc} = 0.4$
- Low density case: 10 clusters
- High density case: 30 clusters
- 50 users per clusters
- 500 general users
- $P_{LOC} = 0.2P_{BS}$

Type of call is not important, we consider only a snapshot of one superframe and analyze data.
Simulation Results

Throughput

Pathloss Exponent $\alpha$

Throughput Gain

Low Density

High Density

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Low Density
Simulation Results

Power Consumption

Pathloss Exponent $\alpha$

Power Consumption

Low Density

High Density

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Simulation Results

Power Consumption

Pathloss Exponent $\alpha$

- Low Density

Power Consumption

0.8
0.75
0.7
0.65
0.6

2
3
4
5
6
Simulation Results

Power Consumption

Pathloss Exponent $\alpha$

Power Consumption

Low Density

High Density
Benefits from our Scheme

Contributions

- Proposals for bypassing BS and reusing resources
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Benefits from our Scheme

Contributions

- Proposals for bypassing BS and reusing resources
- Mathematical formulation of the cell
- Algorithm for implementing these ideas
- Simulation results showing significant gains
Future Work

Where to go from here?

- Add shadowing, more complex terrain
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- Tighter $d_{\text{min}}$ computation
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Thanks!

Any further questions?

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Thanks!

Any further questions?