A Distributed Resource Block Assignment Scheme for Relay-Assisted Cellular Networks With Self-Organizing Terminal Relays
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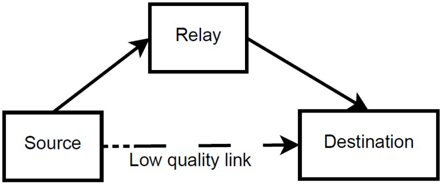
Introduction–Overview

- Advanced cellular services spurred an increasing demand.
- Bringing the base station (BS) closer to the user is inevitable.
- How?
  - Heterogeneous network employing relays, femtocells, CoMP,. . . etc.
- The scope of our work is relaying.

Introduction–Relays

- Advantages:
  - Improving links quality
  - Extended coverage
  - High data throughput
  - Easy to install in strategic locations
  - Low cost
- Disadvantages:
  - More complex network
  - Difficult to coordinate the assignment of resource blocks



Introduction–Coordination

- Centralized coordination is plausible for small numbers of fixed relays.
- Number of fixed relays increases with the increase in the number of user terminals.
- Associated cost and coordination overhead might not be practical.
- An effective solution is to exploit terminal relaying.

Introduction–Terminal relaying

- Idle terminals can relay signals of active ones in a cooperative manner.
- Their large number and incidental access renders their coordination a cumbersome task.
- Centralized coordination by BSs may not be practical.
- More efficient resource blocks (RBs) coordination schemes is required.

Related work

- [Mishra, 2004] Clustered frequency reuse structure in GSM.
- [Koutsimanis *et al.*, 2008] Random based dynamic RBs assignment.
- [Mubarek *et al.*, 2005] Dynamic frequency allocation in frequency hopping schemes.
- [Etkin *et al.*, 2007] Game theory based assignments.
- Can these schemes be applied in a network that employs terminal relaying?

Problem statement

- Acquiring CQIs in terminal relaying systems may not be practical.
- How to efficiently coordinate the assignment of Resource Blocks?
- Given that
  - No channel quality indicators (CQIs).
  - Large numbers of RTs and WTs.
  - Terminal relays have limited processing and communications capabilities.
  - Centralized coordination is cumbersome.
- Solution:
  - RTs must autonomously assign their resources.

End goal

- Due to absence of CQIs and centralized coordination overlap in the RBs assignment will occur.
- An overlap will result in a high level of intra-cell interference.
- How to minimize the number these occurrences while some RBs are still not assigned?
- Develop a scheme that can :
  - Autonomously coordinate the assignment of RBs in a distributed fashion.
  - Accommodate arbitrary user distributions by allowing each relay to have access to all available RBs.
  - Efficiently assign the available RBs to wireless terminals.

Optimal case: 2-relay example

- Given N RBs.
- Relay 1 assigns its resources to its k_1 incoming users in the order $r_1, r_2, ..., r_{k_1}$.
- Relay 2 assigns its resources to its k_2 users in the order $r_N, r_{N-1}, ..., r_{N-k_2+1}$.
- An overlap occurs when $k_1 + k_2 > N$.
- Can it be extended to more than 2 relays?

Background

Definition

Groups:
A group is a set G on which the closure property is satisfied:
For all $(x, y) \in G \times G$ the element $xy \in G$.

- Cyclic groups.
- Type of groups depends on group operation (e.g., additive, multiplicative).

Primitive Roots

- The set $\{1, \ldots, n-1\}$ forms a multiplicative cyclic group under modulo n multiplication if $n = P$ where P is a prime number.
- The group generators are the primitive roots of P.
- A primitive root is a number that generates a sequence of all the elements of the group.

$$(g_i^{k_1} \pmod{P}, \ldots, g_i^{k_{p-1}} \pmod{P}) = (1, \ldots, P-1)$$

$$k_i \in \{1, \ldots P-1\}, i = 1, \ldots, P-1$$

Primitive Roots

- Lemma: There is no cyclic shift for which the sequence generated by g_1 coincides with the sequence generated by g_2.
- An additional degree of freedom arises which is cyclic shifts.
- In this case the new sequence becomes:

$$(g_i^{k_1+s_i} \pmod P, \ldots, g_i^{k_{p-1}+s_i} \pmod P) = (1, \ldots, P-1)$$

$$1 \leq s_i \leq P-1$$

System model

- Consider a system with M relays and N RBs.
- Relays are not capable of communicating with each other.
- Users access the system according to a counting process.
- CQIs are not available at relays.
- We define the hit (collision) occurrences as the occurrences at which an RB is assigned to multiple wireless terminals.
- Performance can be improved by reducing interference.
- Our design metric is the average number of hits.

Primitive roots based scheme

- For simplicity we assume that the number of RBs is $P - 1$ where P is prime.
- A primitive-root-cyclic-shift (PRCS) pair is assigned to each relay.
- Relays follow a locally generated prescribed sequence in assigning the resources.
- Each relay has access to the entire pool of RBs.

Choosing the PRCS pairs

- There is no guarantee that the chosen sequence is the best over all possible combinations of sequences.
- We can guarantee that the chosen sequences are the best performing cyclic sequences.
- The PRCS selection process is performed offline prior to the system start-up.
- How to efficiently choose the PRCS pairs?
- A metric is proposed for a fast and relatively accurate choice of PRCS pairs.
- A graphical PRCS selection technique is proposed to further improve the metric proposed.
- Objective: Minimize average number of hits.

Further improvement

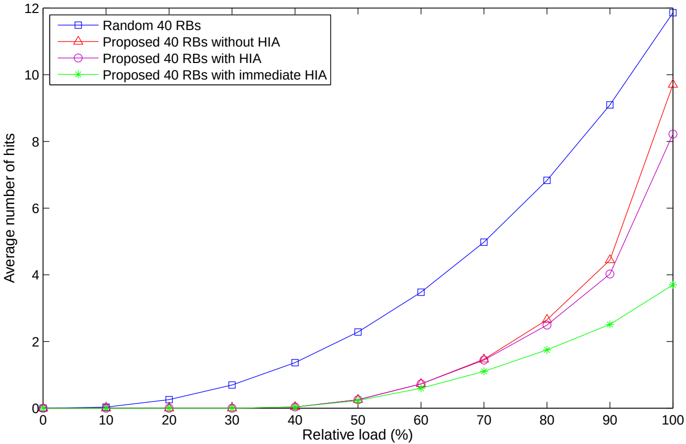
- Due to lack of coordination, the number of hit occurrences can only be minimized and not completely eliminated.
- These occurrences can be utilized to further improve the performance using the proposed hit identification and avoidance (HIA) algorithm.

HIA algorithm

- Each relay is aware of the PRCS pairs adopted by its neighboring relays.
- When a hit occurs relays infer from the generated sequences the hit source with which they collided.
- With the sequence known and the hit source identified future hits can be avoided unlike the case when random assignment is adopted.
- Better avoidance can be achieved if relays are capable of immediately identifying the hit source.

Simulation results

- Number of relays $M = 3$, number of RBs $N = P - 1$.



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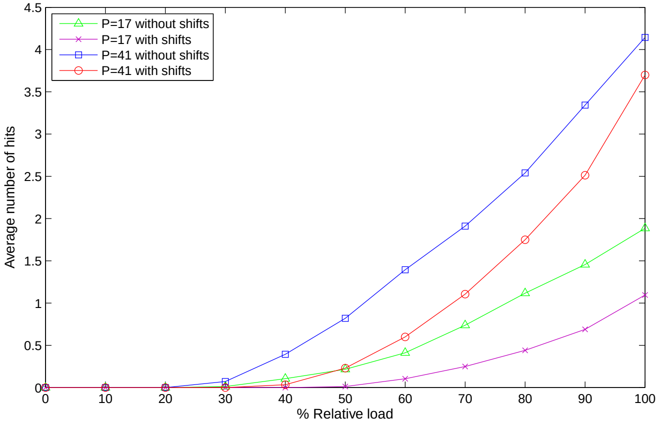

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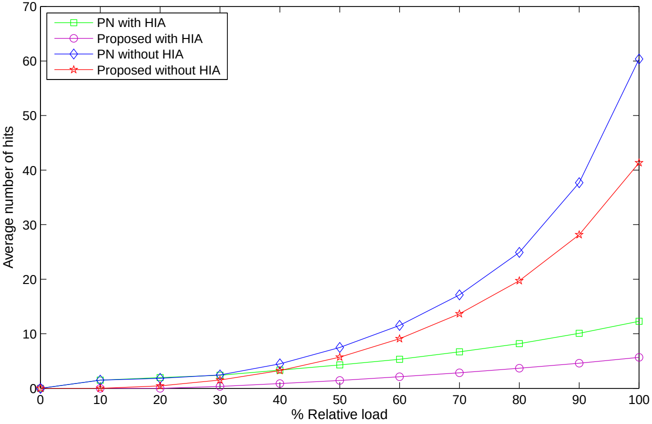

Conclusion

- In this we proposed an autonomous assignment scheme for terminal relaying based cellular systems.
- The RBs assignment is flexible to accommodate non-uniform user distributions.
- The RB assignment Sequences is generated locally from a single PRCS pair.
- CQIs are not required.
- Coordination overhead is negligible.

Conclusion–Cont.

- Sequences enable information extraction (e.g. load in neighboring relays) when a collision occurs.
- Simulations indicate that the larger the number of RBs, the higher the gain of our scheme relative to the PN-based and uniformly distributed random assignments.
- The proposed RBs assignment scheme is not limited to cellular networks.

Future Work

- Implementing a trellis diagram approach in the HIA algorithm to improve its performance.
- Extending the proposed graphical PRCS selection technique.
- Investigate the effect of employing occasional spectrum sensing on the performance of the proposed HIA algorithm.

Publications

- Yaser Fouad, Ramy Gohary, and Halim Yanikomeroglu, "A Resource Block Assignment Scheme For OFDMA-Based Cellular Networks With Self-Organizing Terminal Relays," in *Proc. IEEE Vehic. Tech. Conf. (VTC2011-Spring)*, (Budapest), May 2011.
- Yaser Fouad, Ramy Gohary, and Halim Yanikomeroglu, "An Autonomous Resource Block Assignment Scheme For OFDMA-Based Relay-Assisted Cellular Networks", under review in *IEEE Trans. Wireless Commun.* (submission: 18 October 2010, 1st results: 01 January 2011, 1st review submitted: 01 March 2011, 2nd review: in progress).

Metric for choosing the PRCS pairs

- A load matrix $X(g_i, s_i)$ is generated for each RT i.
- For each pair of relays i and j a pairwise hit matrix, $H_{i,j}$, is calculated.
- For a specific load of M relays, the number of hits, $Z(k_1, \ldots, k_M)$, is calculated.
- The average number of hits given all possible combinations of relay loads, $C(K)$ is calculated.
- We choose the PRCS pairs that minimize the value of $C(K)$.

Graphical selection of the PRCS pairs

- How can we further improve the selection process?
- A graphical PRCS pairs selection technique is proposed.

Graphical selection of the PRCS pairs

- A group generator is chosen to be the circle basis.
- The graph representing the cyclic group is constructed.
- The group generators and their inverses are grouped into pairs (g, g^{-1}).
- One group generator of each pair is used to construct a pattern.

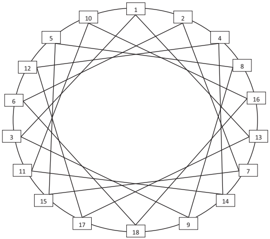

Figure: Graphical representation of a cyclic group of order 18.

Graphical selection of the PRCS pairs

- The pattern is shifted with all possible shifts.
- Another group generator is selected to construct its pattern.
- The group generator and the cyclic shifts yielding the minimum number of hits are selected.

HIA, an example

- Consider the case where $P = 17$, $s_i = 0$, $i = 1, 2, 3$ and $g_1 = 3$, $g_2 = 5$ and $g_3 = 6$.

(g_1, s_1)	3	9	10	13	5	15	11	16	14	8	7	4
(g_2, s_2)	5	8	6	13	14	2	10	16	12	9	11	4
(g_3, s_3)	6	2	12	4	7	8	14	16	11	15	5	13