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A Hypothetical Wireless Network with Mobile Base Stations in Urban Areas

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ABSTRACT

A wireless network is proposed for densely populated areas served by public transportation units (PTUs) in which the base stations are mounted on the PTUs and are thus themselves mobile. The advantages of having such mobile base stations are pointed out, and the proposed architecture is studied, first for a simple geometry, and then for more complex layouts as are found in urban areas. The features of the transportation model, the propagation model, and the communication model are discussed. Results for the simple model with a rectangular geometry and line-of-sight (LOS) propagation are given, work is ongoing on a more general model with non-LOS propagation, various quality-of-service (QoS) properties, and resource allocation and the associated cost analysis, for two wireless technologies, CDMA and TDMA.

1. OVERVIEW

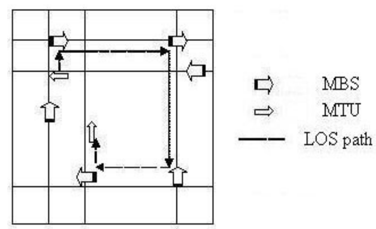
In a conventional cellular network, base stations (BS) are laid out in a hexagonal pattern with each BS serving a hexagonal cell whose side decreases inversely with the size of the population covered [4]. In dense urban areas a macrocell is replaced by a larger number of microcells with lower power base stations, usually located at the intersections of streets. In downtown areas with a large number of multistoried buildings, a microcell is overlaid with a network of picocells with very low power base stations on the floors of a multistoried building. The ongoing work reported here describes a model of urban wireless communication at the street level using base stations that are themselves mobile. These moving base stations (MBS) are mounted on public transportation units (PTU) that move along fixed paths in an urban transportation grid. Initially the transportation model restricts the PTU routes to a rectangular grid; this restriction is removed in a subsequent more detailed model. Likewise the propagation model initially assumes signal propagation paths to be line-of-sight (LOS) through a set of MBSs, this too is later relaxed. For the simple model, conditions for continuous communication between two MTUs are derived. The extended propagation model considers non-line-of-sight propagation, including reflection, diffraction, and propagation through buildings [1]. The communication model of the network looks at two technologies, CDMA and TDMA. Analysis of different aspects of radio resource management [5] including load factor, various quality-of-service (QoS) parameters for voice, and dependence on PTU service patterns is ongoing.

2. A NETWORK OF MOBILE BASE STATIONS

Wireless communication in an urban area is modeled with a dynamic non-cellular network overlaid on the fixed macrocellular network. It consists of mobile base stations (MBSs) that move along fixed routes in an urban transportation system. A MBS can be implemented with a transceiver and antenna mounted on a PTU such as bus, tram, cable car, and surface (and possibly subway) train. At the street level an MTU communicates with another MTU in the urban area directly through the MBSs without going through a macrocell BS. (It has still to go through one of the latter to communicate with an MTU outside the MBS coverage area or with the backbone.) In a dense urban area, this could have several potential advantages:

1) the lower cost of serving dense MTU clusters on the street;
2) the corresponding savings in power and bandwidth at the macrocellular BSs (the latter are involved only in billing and security operations); and
3) ease of maintenance of the MBSs.

Figure 1. Simple Wireless Network Geometry



Interestingly, the service patterns of the PTUs tend to intrinsically reflect MTU density in space and time in an urban area. Since the routes followed by MTUs on the streets are fixed and generally along the lines of the urban transportation grid, the communications properties of such a network are easy to study for simple propagation models.

The following are examples of questions that are of interest in modeling and design of such a network:

1) What are the required conditions for two MTUs A and B to communicate with each other?
2) What are the movement patterns of the MBSs (equivalently the service patterns of the PTUs on which they are mounted) in order for A and B to have uninterrupted service?
3) What is the minimum number of MBS's required for different propagation assumptions?
4) For a given number of MBS's how many MTUs can be served at any given time?

Answers to some of these questions have been obtained; others are currently the object of this ongoing study. They are based on techniques from computational geometry [3], mobile communication [2], and radio resource management [1, 5].

Figure 2. Example of Extreme LOS Path

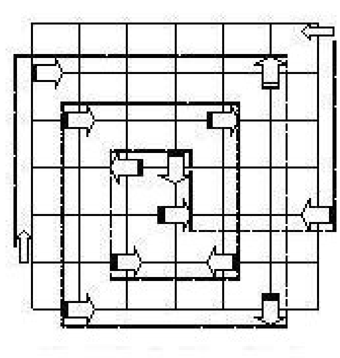


Figure 3. Minimum Coverage Example

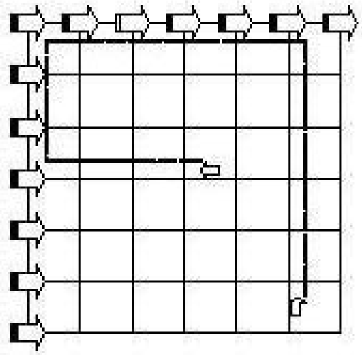
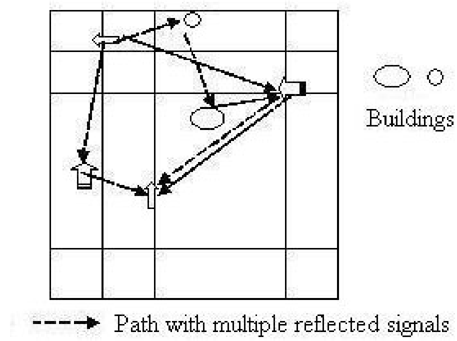


Figure 4. Multipath example



3. A SIMPLE MODEL

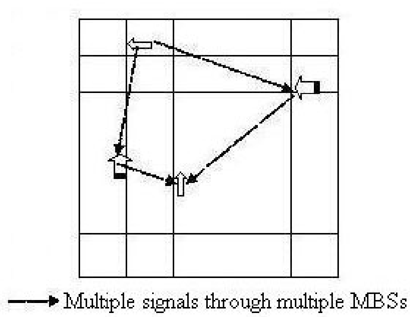
The following assumptions are made:

1) an MBS moves along a horizontal path or vertical path only (but not both) at all times;
2) the mode of propagation is line of sight (LOS);
3) the grid is a lattice with integer addresses (x, y); 1 £ x, y £ N.

None of these conditions is necessary; they are used only to simplify this first model and its analysis. The following results can be derived using simple network analysis and computational geometry techniques:

1) At any given time MTU A at (x,y) can communicate with MTU B at (w,z) if there is a LOS path through one or more MBSs such that each pair of MBSs communicate through LOS.
2) The maximum communication delay along a path with distinct MBSs between A and B is of order $O(N^2)$.
3) The minimum number of MBSs for full coverage at all times is 2n-1.
4) Given a set of MBSs they can be partitioned into connected subsets where a connected subset is one in which any two MBSs can communicate through a LOS path. A can communicate with B if and only if both are connected to at least one and the same partition of the MBSs. When A is connected to (that is, communicates with an MBS in) partition X and B to partition Y, X¹Y, the minimum number of connections required for A to be able to communicate with B is also a shortest path from X to Y.
5) An MBS (on a PTU) moves along a grid line and is always visible along the line. It becomes visible along a perpendicular grid line when it crosses an intersection, with the duration of visibility determined by the time it remains in the intersection (which may include the time it may stand at a service point such as a bus stop or tram stop). This behavior is modeled with a visibility function $V_{X\ (or\ Y)}$ (y (or x), t), which, for a uniform grid size, is (approximately) a rectangular periodic pulse train. Then the visibility pattern function V(t) for the set of all MBSs is the boolean AND of all the individual visibility functions. A call between two MTUs will complete if and only if V is unity over the duration of the call.

Figure 5. Example of multipath with reflections



4. A MORE COMPLEX MODEL WITH NON-LOS PROPAGATION

The assumption of full coverage through a set of PTUs being present at intersections at all times (which is necessary in the simple model for an unbroken call) is of course not realistic. Also, PTU routes usually do not pass over all streets. However, with sufficient signal levels at an MTU and sufficient link power at the MBSs these problems are circumvented. Thus radio signals on direct non-LOS paths (typically passing through buildings and other obstacles) can have sufficient strength to provide full coverage at all times whenever and wherever PTU service is available. When such service ceases or is reduced (usually after normal business hours) communication can switch to the underlying cellular network. Since this change occurs along with a drop in call density (mirroring the lower off-peak usage seen in land-line usage) an overall savings in bandwidth and power over a 24-hour period can be expected.

An extended analysis that is ongoing includes the following:

1) Transportation model: a) PTU service is assumed not to blanket the entire area, and b) PTU service patterns are used to coordinate service with the above mentioned step of switching to the cellular network.
2) Propagation model: properties studied include multipath (including reflection and diffraction), fading (slow and fast, due to mobility of both MTU and MBS), path loss in open air and wall penetration, and required link budgets. Two urban radio propagation models are appropriate: Walfisch and Ikegami's COST, and IMT2000 [1].
3) Communication model: effects considered include channel coupling due to interference between multiple MBS transmissions and the near-far effect from nearby MTUs. Two technologies are considered: CDMA and TDMA.

Based on the above analysis appropriate parameters for radio resource management (capacity management and resource allocation for a desired QoS) will be derived and a cost model constructed. It is hoped that tangible results will be available shortly.

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