Chapter 3

System Simulation

In the previous chapter we have performed an analytical investigation of topics that arise when mobile information access is improved by situation awareness. In this chapter we present the methods and results of our simulations, which were performed for the purpose of extending the previously obtained analytical results towards a system level perspective and more complex scenarios.

Since we are especially interested in the effects of situation aware prefetching for mobile information access in heterogeneous wireless networks, a **network model** (3.1) is required in which **user mobility** results in **network topology changes** (3.1.1). Furthermore, **resource sharing** among multiple users (3.1.2) has to be considered. For the purpose of generating realistic user mobility a novel **mobility model** is presented (3.2), which comprises **path generation** (3.2.1), **speed generation** (3.2.2) and the definition of **coverage areas** (3.2.3). A **model for hypertext documents and traffic** based on Mah's empirical distributions is briefly described (3.3) as a further building block of a realistic simulation environment. Finally the obtained **simulation results** are presented and discussed (3.4) for a **single user scenario** (3.4.1) and various **multi-user scenarios** (3.4.2).

3.1 Network Model

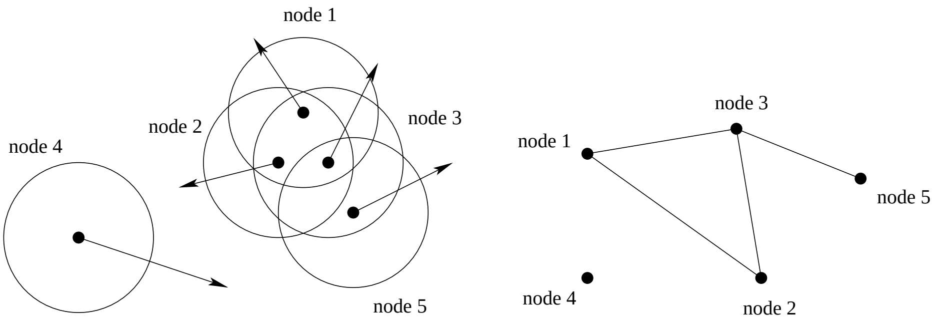
Since we conjecture that situation aware prefetching will be particularly beneficial in mobile scenarios with heterogeneous wireless access technologies we will start by defining an appropriate network model for our simulations. The mobility of the user in combination with finite coverage regions constantly causes changes in the network topology. Typically the network topologies changes too frequently to burden the user with the necessary reconfiguration. Therefore we require the system to perform automatic topology establishment and dynamic topology maintenance.

3.1.1 Topology and Mobility

A definition of the network topology helps us to describe the scenarios under investigation within this work. We use the abstraction of *adjacency* between nodes. Two nodes are adjacent if they can establish connections and communicate in both direction with each other[1]. With this definition we can visualize the topology at a given time instant t by an un-directed graph $\mathcal{G} = (\mathcal{V}, \mathcal{E})$, where all nodes form the set of *vertices* $\mathcal{V}$ and the available links form the set of *edges* $\mathcal{E}$. The state of the topology can be condensed into the symmetric *adjacency matrix* $\mathbf{A}(t) = [a_{ij}(t)] = [a_{ji}(t)]$ of the graph $\mathcal{G}$, where $a_{ij}(t) = a_{ji}(t) = 1$ if node i and node j can communicate with each other at time instant t and $a_{ij}(t) = a_{ij}(t) = 0$ if not.

An example is given in Fig. 3.1. The corresponding adjacency matrix for the depicted time instant is

$$\mathbf{A} = \begin{pmatrix} 1 & 1 & 1 & 0 & 0 \\ 1 & 1 & 1 & 0 & 0 \\ 1 & 1 & 1 & 0 & 1 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & 1 \end{pmatrix}$$



(a) Nodes and coverage regions (b) Topology graph $\mathcal{G}$

Figure 3.1: *Dynamic network topology of ad hoc nodes. Node mobility (speed, direction) is indicated by arrows. At each time instant the nodes' current location in conjunction with their communication range leads to a particular topology*

Typical assumptions in ad hoc networking are the lack of any fixed infrastructure, the equality of all participating nodes in terms of mobility and communication technologies and the ability of mobile nodes to directly connect with each other. While in this work we consider frequently changing ad hoc connections between nodes we do

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[1] Depending on the wireless technology communication may still be possible in one direction but not in the other, due to asymmetries e.g. transmission power on mobile and base station. However, in this work, we are considering only the case where connection-oriented protocols with ARQ are employed. With these protocols a link has to be considered broken, whenever communication in one or both directions is impossible

not treat ad hoc network systems that follow the previously stated typical assumptions. Instead a combination of a globally available mobile network with only locally available short range access points and a hierarchical network structure is investigated. The set of vertices in the graph $\mathcal{G}$ can then be partitioned into four subsets $\mathcal{V}_m, \mathcal{V}_r, \mathcal{V}_c$ and $\mathcal{V}_s$ representing mobile nodes (mobile devices), resident nodes (access points), central nodes and server nodes. The number of elements in the four sets is denoted by $N_m = |\mathcal{V}_m|,\ N_r = |\mathcal{V}_r|,\ N_c = |\mathcal{V}_c|$ and $N_s = |\mathcal{V}_s|$.

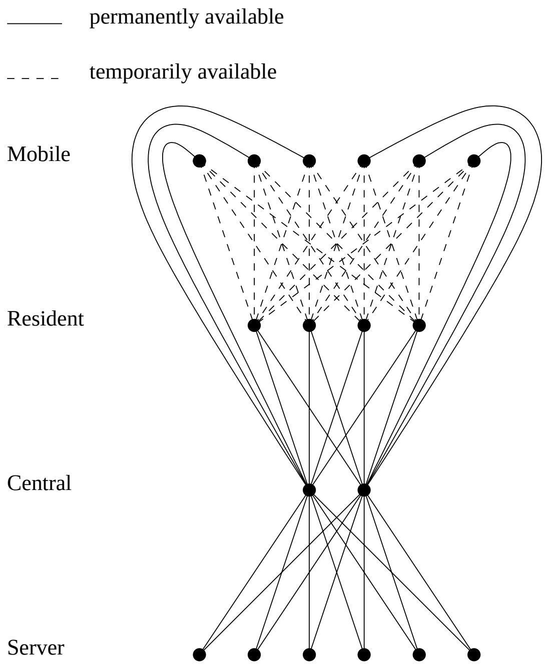

Figure 3.2: *Hybrid hierarchical network topology*

Given this partition and the structure depicted in Fig. 3.2 the adjacency matrix $\mathbf{A}(t)$ can be viewed as being composed of several sub-matrices with each sub-matrix describing the connection between the subsets of nodes or vertices:

$$\mathbf{A}(t) = \begin{pmatrix} \mathbf{A}_{M,M} & \mathbf{A}_{M,R}(t) & \mathbf{A}_{M,C} & \mathbf{A}_{M,S} \\ \mathbf{A}_{R,M}(t) & \mathbf{A}_{R,R} & \mathbf{A}_{R,C} & \mathbf{A}_{R,S} \\ \mathbf{A}_{C,M} & \mathbf{A}_{C,R} & \mathbf{A}_{C,C} & \mathbf{A}_{C,S} \\ \mathbf{A}_{S,M} & \mathbf{A}_{S,R} & \mathbf{A}_{S,C} & \mathbf{A}_{S,S} \end{pmatrix} \tag{3.1}$$

Since all other connections are either permanently available or permanently unavailable, only the connections between mobile nodes and resident nodes result in time dependent sub-matrices $\mathbf{A}_{M,R}(t)$ and $\mathbf{A}_{R,M} = \mathbf{A}^T_{M,R}(t)$. If we denote the all-one and all-zero matrix of dimension $n \times m$ by $\mathbf{1}_{m,n}$ and $\mathbf{0}_{m,n}$ and the identity matrix of dimension $n \times n$ by $\mathbf{I}_{n,n}$ and use the symmetry of the links we can see that for the hybrid hierarchical network topology