CHAPTER I

Introduction

Wireless mobile communication has become prevalent in the globalization era. In this work, we consider a theoretical mobility model in a two-dimensional grid proposed by Greenlaw and Kantabutra to be our model and investigate a few interesting problems. We also extend the model to three-dimensional grid and investigate a problem related to the new model.

1.1 Statement and Significance of the Problem

Mobile wireless communication has seen an explosive growth in recent years. The total global mobile phone and smartphone market is projected to be worth 341.4 billion US dollars by 2015. In a short period of time, a large number of research papers have covered mobile wireless communication. According to Google Scholar, at least 1,070,000 papers have studied some aspects of mobile wireless communication thus far. In Chapter III we are particularly interested in the coverage problem in this kind of the communication. The coverage is the area in which mobile wireless communication among devices can take place. Therefore, it is important to study this problem and several researches have dealt with coverage in the mobile wireless communication. Huang and Tseng studied a decision problem to determine whether every point in the service area of the sensor network is covered by at least k sensors and presented polynomial-time algorithms that can be translated to sensors-distributed protocols [1]. Tian and Georganas investigated a wireless sensor coverage problem and proposed a node-scheduling scheme to reduce the overall system energy consumption by turning off some redundant nodes [2]. Traditionally, transceiver locations in the indoor wireless communication systems are selected by human experts to have the greatest coverage possible. Panjwani et al. proposed an interactive software system that assists in transceiver placement in a multifloored indoor environments [3]. Wang and Tseng studied how to efficiently deploy sensors to cover an area and solved the K-COVERAGE SENSOR DEPLOYMENT PROBLEM to achieve multi-level coverage of a given area [4]. Wang et al. discussed novel protocols that can dynamically configure a network to achieve guaranteed degrees of coverage and connectivity and provided both geometric analysis and simulations to support the use of their protocols [5]. Fan and Jin discussed the AREA COVERAGE PROBLEM in wireless sensor networks [6]. This problem is to determine whether all points in a region are covered by a given set of sensors. Their solution uses the transformation of the area coverage problem to the simpler and more suitable INTERSECTION POINTS' COVERAGE PROBLEM. Zorbas et al. described algorithms to solve various coverage problems [7]. These algorithms were based on the concept of cover sets, where each cover set is capable of monitoring all targets. In the field of computational geometry, the problem called DISK COVERAGE PROBLEM asks for the smallest radius $r(n)$ required for n equal disks to completely cover the given unit disk [8]. Acharyya et al. discussed UNIT DISK COVER PROBLEM IN 2D [9]. Given a set P of points and a set D of unit disks in the plane such that $\bigcup_{D_i \in D} D_i$ covers all the points in P, the problem is to select a minimum cardinality subset $D^* \subseteq D$ such that each point in P is covered by at least one disk in D^*. These two problems could also be viewed as a coverage problem in the wireless communication model. For more information about various coverage problems, we suggest a nice survey in [10] by Ghosh and Das. In Chapter III we propose a problem called MAXIMUM POINTS COVERAGE PROBLEM (MPCP) in wireless communication. Given m sources on a two-dimensional grid and each source covers a circular area and has a radius of one, the problem is to determine the maximum number of grid points that can be covered by the m sources while all the m sources must maintain communication among themselves. Our problem is different from the existing problems in literature because it is based on a two-dimensional grid, and the covering of sources must enable communication among the m sources. We are also interested in laying minimum number of sources to cover some particular grid points and define GRID POINTS COVERAGE PROBLEM (GCP) in Chapter IV. However, we scope our area into a square and propose SQUARE GRID POINTS COVERAGE PROBLEM (SGPC) [11] to minimize number of sources with coverage radius of one to cover a square grid point size of p without obstacle with the restriction that all the sources must be communicable. APPROX-SQUARE-GRID-POINTS-COVERAGE (ASGC) [11] is an approximation algorithm for SGPC, and it will be useful if the status of SGPC is *NP*-

complete. ASGC uses the rule that any number can be obtained from the addition of 3, 4 and 5, so we combines 3-gadgets, 4-gadgets and 5-gadgets to specify the position of sources to cover a square grid point size of p and achieves an approximation ratio of $1+\frac{p-2}{p^2+2}$ and $1+\frac{2p-10}{p^2+2}$ when $5<p\leq 8$ and $p>8$, respectively. Also, there are many researches particularly interested in the complexity aspect of pairwise simultaneous communication in the wireless mobility model. Blazewicz et al. in their pioneering work showed that obtaining simultaneous and timely access to multiple resources is *NP*-complete [12]. Dated back to 1986, where mobile wireless communication were not widespread. Karaman and Hassanein discussed the known *NP*-complete problem of the delay-constrained multipoint communication with multiple sources in a distributed environment and provided potential solutions to the problem [13]. This problem is to find a set of paths connecting a given set of sources to receivers so that no path connecting a source-receiver pair violates the delay bound and the total number of links in the set of paths is minimized. In [14] Greenlaw et al. discussed the two-dimensional mobility model on a grid. Their model incorporates elements such as users, access points, and obstacles so that it faithfully mimics the real environment. Three problems involving three real situations were proposed and solved. To extend the mobility model of Greenlaw and Kantabutra to three-dimensional model to cover the more realistic situation, we discuss the extension of their model to three dimensions in Chapter V. In this section, the extension of the wireless mobility network model in [14] to a three-dimensional grid and introduces a communication protocol in the network is proposed. MULTI-SOURCES SIMULTANEOUS COMMUNICATION PROBLEM (MSSCP) is defined and the proof to show that this problem is *NP*-complete is stated [15, 16]. The intuitive reduction to show that MSSCP is *NP*-complete is discussed. All necessary gadgets in the construction are introduced, and the detailed construction of the instance from these gadgets is described, and then the *NP*-completeness proof of MSSCP and its related lemmas are shown. Observe that our problem is different from that of Blazewicz et al. because their problem involved scheduling while ours is not a scheduling problem. Our problem is also different from the delay-constrained multipoint communication with multiple sources in a distributed environment of Karaman and Hassanein because our problem is not to find a set of communication paths that has a minimum number of links and does not involve any kind of delay bound. Lastly, conclusions, a list of open problems, and the future researches in the model are stated.

The maximum grid area that can be covered by the communicable sources with the same radius equal to one and the lower bound number of the sources that can cover a square grid points are presented in Chapter III. The definitions and an approximation algorithm for SGPC are presented in Chapter IV. The extension of the mobility model to a three-dimensional grid and the proof to show that MSSCP in the three-dimensional grid is intractable is presented in Chapter V. Conclusions of the contributions of this dissertation and the future work for mobile wireless network are referred in Chapter VI.

1.2 Objectives

In this section, we briefly summarize the objective of our work:

- To find the maximum grid area that can be covered with the communicable sources with the same radius equal to one.
- To find an approximation algorithm to give an approximate solution for SGPC to cover grid points in a square area with no obstacle in two-dimension in cases all sources have the same radius equal to one and all sources must be communicable.
- To propose a three-dimensional grid mobility model that is extended from the theoretical mobility model in a two-dimensional grid proposed by Greenlaw and Kantabutra.
- To show that MSSCP in the three-dimensional grid is intractable.

1.3 Outcomes of this Study from Theoretical Perspectives

The outcomes of our research as listed as follows:

- The maximum number of grid points that can be covered by sources with the coverage radius of one with the restriction that all sources must be communicable in both the infinite grid and the square grid.

- The lower bound number of sources with the coverage radius of one to cover all grid points in a square grid.

- An approximation algorithm with an approximation ratio for SGPC to cover square grid points in a two-dimensional grid with no obstacle in cases of all sources have the same radius equal to one and all sources must be communicable.

- Three-dimensional mobility model for mobile wireless network that is extended from the theoretical mobility model in a two-dimensional grid proposed by Greenlaw and Kantabutra.

- *NP*-complete proof of showing the intractability of MSSCP.

- New knowledge about wireless network theories that potentially can be adopted to real applications and be used to improve the efficiency of wireless networks.

1.4 Scopes of Study

The scope of our study is as follows:

- The mobility models that we use are based on the mobility model of Greenlaw and Kantabutra.

- We consider two and three-dimensional discrete models.

- To define problems related to the mobility models.

- To classify and solve problems base on the method of proof and the complexity theory.

1.5 Research Design and Methods

We briefly described our methodology next:

- Gain knowledge by reading papers, examine the mobile wireless network in a two-dimensional grid for studying wireless communication, wireless networking, graph theory, the growth of functions, the methods of proofs, and the complexity theory.

- Gain insight into these problems, define some problems and models.

- Find the status of the problems. If a problem is tractable, there is a polynomial time algorithm to solve it. Otherwise, prove that the problems are intractable by making a reduction from an *NP*-complete problem.

- For tractable problems, find asymptotic efficiency and prove correctness of the polynomial time algorithms that we have. For an intractable problem, find an approximation algorithm to give an approximation value that is close to the optimal values or solve some particular cases in polynomial time.

1.6 Summary

In this chapter we state the significance, the objectives, the outcomes, the scopes, and the processes of this dissertation. In the next section, we will describe the necessary knowledge that must be used in this dissertation.