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Coverage Improvement for Wireless Sensor Networks using Grid Quorum based Node Mobility

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Abstract

Coverage of wireless sensor networks (WSNs) is an important quality of service (QoS) metric and often the desired coverage is not attainable at the initial deployment, but node mobility can be used to improve the coverage by relocating sensor nodes. Unconstrained node mobility is considered infeasible based on the high locomotion cost that would nullify the advantage likely to be gained with the coverage improvement. Coverage improvement based on node mobility depends on many parameters including number of deployed nodes (static and mobile), proportion of mobile nodes, permissible distance the mobile nodes can move and the total distance nodes moved to attain certain coverage. The contribution of this paper is the investigation of the inter correlation of all these parameters for a grid-mesh architecture based on the grid quorum scheme. Having such information available prior to the practical deployment is a major advantage when designing the network, this can help improve both operation and cost.

Keywords: Sensor coverage; grid quorum; deployment; node mobility; sensor networks

1. Introduction

Coverage in wireless sensor networks (WSNs) is a basic quality of service (QoS) metric and relates to the capacity of the network to sense the region or area of interest for a certain application [1, 2]. The attained coverage initially depends on the node deployment, which could be either deterministic or random [3] and is commonly referred to as the “sensor network deployment” problem. Achieving an optimal/proper coverage utilizing the minimum number of nodes is an NP-hard problem [4].

Effective coverage can be attained using more nodes than the required critical density [5]. Alternatively, mobile sensor nodes can be used which can relocate to fill in coverage holes or deficit regions. Coverage improvements in WSNs using node mobility schemes can be broadly categorized into virtual force, coverage pattern and grid quorum

based movement strategies [10]. Compared with the virtual force and coverage pattern node mobility schemes, the grid quorum movement scheme does not require precise movement location for sensor nodes as nodes are moved between regions. By doing so, complex localization techniques [6] can be avoided saving both cost and energy.

Utilization of mobile sensor nodes for coverage improvement is useful but has its own limitations. Mobile sensor nodes are more expensive than static sensors and, compared with communication or sensing tasks, mobility consumes more energy. Mobility is also constrained due to practical reasons and the excessive energy consumption related to the mobility. As a result, mobile nodes are only able to traverse shorter distances in order to not completely deplete the node’s energy in locomotion [7, 8].

In this paper, the focus is on hybrid WSNs comprised of both static and mobile nodes and the investigation of the tradeoff between the coverage and the node mobility. The novelty includes the investigation of node mobility to improve coverage considering an initial random deployment (initial coverage) attained by a number of nodes of which a proportion are mobile, but are constrained in the permissible distance moved. The inter correlation for these parameters is analyzed for a grid-mesh architecture based on a grid quorum scheme. The results provide guidelines for dimensioning and designing WSNs to be deployed in real-world sites to utilize resources in terms of the initial investment and deployment in a more efficient manner.

The paper is organized as follows. Section 2 highlights the related work, and Section 3 describes the functioning of the grid quorum movement scheme and simulation setup. The results are presented in Section 4 and concluding remarks are given in Section 5.

2. Related Work

Coverage improvement using node mobility has been studied extensively [7-11] and it has been concluded unlimited mobility is not feasible [7-9]. In [12], the tradeoff between the density of mobile nodes and network performance measures has been investigated with respect to detection probability, detection latency and mean first contact distance for target detection, but without considering coverage-node mobility parameters. Coverage improvement based on the grid quorum scheme was first presented in [11] and, based on this, [13] proposed a mechanism to minimize the total distance moved by the nodes by investigating the number of moves and convergence rate. However, the mechanism did not include constrained mobility and the corresponding coverage and influence of variable permissible distance on coverage were not included. An upper bound on the mobile density required for attaining k-coverage and the maximum distance a single node has to move has been presented in [7].

The unique novelty of the work presented in this paper is the investigation of all possible values for the inter parameter relation determined across the complete range of the parameters considered. To the best knowledge of the authors this paper is the first of its kind for determining all the inter parameter relations governing coverage improvements using node mobility.

3. Methods

3.1. Grid Quorum

The goal of the grid quorum node movement technique is to minimize the overall distance moved and to achieve a balanced state in terms of overall coverage. By analyzing the deployment region as a virtual graph, the grid cells are modeled as vertices and the distances between the cells as edges [13,14]. This can be modeled as a bipartite graph with uncovered grid cells and grid cells with excess nodes being the two sets of vertices and the movement cost between them being the edges. The objective is to derive a maximum matching between the vertices, while minimizing the matching cost (total edge weight). The matching problem can be represented mathematically [13] with X_{ij} ($i, j=1..n$) being the set of variables, n is the number of nodes in the vertices set of the complete bipartite graph $A = (V, U, E)$, where V, U form the sets of vertices and E the set of edges. $X_{ij}=1$ means the edge v_i, u_j is included in the matching whereas $X_{ij}=0$ means the edge is not included. Hence, the best matching can be found by solving the optimization problem:

$$\begin{aligned} \text{Minimize} \quad & \sum_{ij} C_{ij} X_{ij} \\ \text{Subject to} \quad & \sum_{i=1} X_{ij}=1 \quad i=1, 2, \dots, n. \\ & \sum_{j=1} X_{ij}=1 \quad j=1, 2, \dots, n. \end{aligned} \quad (1)$$

This converts the bipartite graph based matching into a matrix representation with C_{ij} being the assignment cost with the rows of the matrix being vertices in V and the columns being vertices in U . Considering the constrained mobility the assignments in the form of

unique row and column combination which are within the permissible cost as per the mobility distance constraint are taken into account and the rest are discarded.

3.2. Simulation Setup

A uniform deployment region (grid) of 100×100 is considered with 100 grid cells each of size 10×10 . A grid cell is considered covered if at least

one node is within its area. The nodes are assumed to be at the center of the grid cell as the precise location of the nodes is not taken into consideration. The Euclidean distance between the center of the grid cells is used to populate the cost matrix, C , in (1).

The experiment is conducted with the variation in number of nodes from 10 to 500 with increments of 10. The experimental results are mean values for all parameters calculated over 100 runs of the simulation. In constrained mobility, the maximum moveable distance is considered as 7.5, 5.0 and 2.5 units respectively. The number of mobile nodes considered available is varied from 10% to 100 %. The coverage attained, the total and highest distance moved by nodes are observed for change in the input parameters.

4. Results and Discussions

On the basis of the simulation setup of the grid quorum based network deployment, results are grouped into three categories presented in the following three subsections.

4.1. Unconstrained distance mobility and number of mobile nodes

The relation between the coverage obtained with random deployment of nodes and coverage obtained with unconstrained node mobility is as shown in Fig. 1 on the consecutive page.

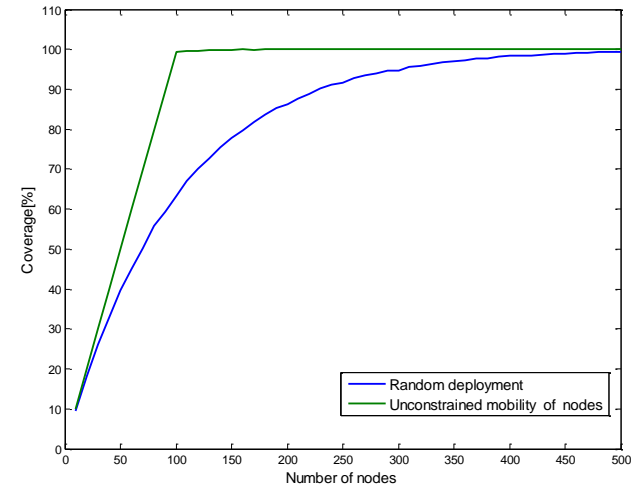


Figure 1 Coverage percentage for random deployment (initial) and based on node mobility

As can be observed from the figure, the number of nodes required to achieve a full coverage (99%) is 460 for random deployment. Therefore in the particular grid quorum based deployment the excess nodes required to achieve full coverage as 360. The total distance moved by the nodes and the highest distance an individual node moved to attain the aforesaid coverage pattern is shown in Fig. 2.

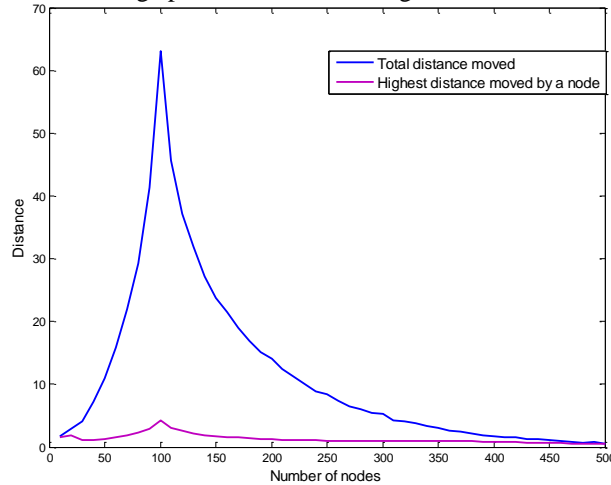


Figure 2 Total and highest distance moved by a node

The total distance moved by nodes is highest for 100 nodes precisely at 63.12 units and the average highest moved distance by an individual node is 4.25 units.

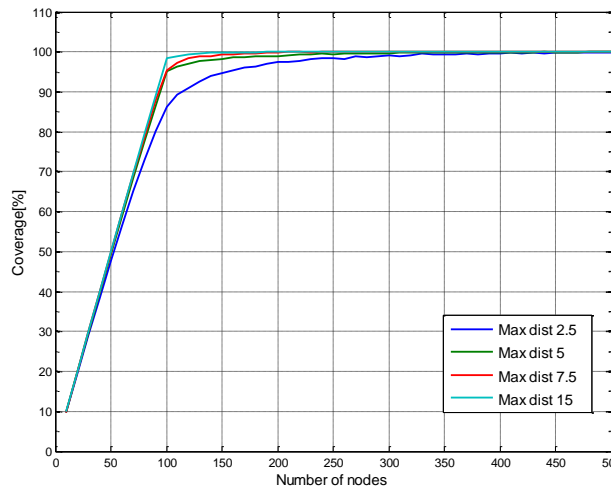


Figure 3 Coverage percent for constrained mobility distance

4.2. Constrained distance mobility

The effect of constrained distance mobility on nodes is shown in Fig. 3-5. It can be observed from Fig. 3 that with a maximum permissible distance of 15, the network attains nearly full coverage with 100 random deployed nodes as the nodes can move unconstrained. The number of nodes required increases with the decrease in the permissible distance and all the possible coverage percentages and the number of nodes required for a particular permissible distance can be observed from Fig. 3. It can be observed that with the permissible distance lowered to 2.5 units the number of nodes required to attain full coverage is as high as 350 nodes.

The total and highest distance moved by a node with the same constrained mobility to achieve the coverage improvement (Fig. 3) is shown in Fig. 4 and Fig. 5. It can be observed that the network nodes reorganize to attain the full coverage at the minimum number of nodes required to attain the full coverage

4.3. Constrained distance mobility and limited number of mobile nodes

Due to cost effectiveness of the network, the number of nodes with mobility should be constrained and only a certain percentage of the total nodes are considered to have mobility. The observations are shown in Fig. 6-9. The total distance moved by the nodes to attain the corresponding coverage (Fig. 6-9) is shown in Fig. 10-13 where the number of nodes required to achieve same coverage with constrained distance mobility respectively plus varying percentage of mobile nodes can be seen. Considering a constrained distance mobility of 2.5 units, the number of nodes required for 90% coverage is 120 while for the same distance constraint and only 10% mobile nodes 180 nodes are required. It is also observed that the coverage pattern for variation in percentage of mobile nodes available is insignificant, when more than 50% mobile nodes are available. There is no significant difference in the total distance the nodes move between the constrained condition of only mobility, and constrained condition of mobility and varying percentage of mobile nodes.

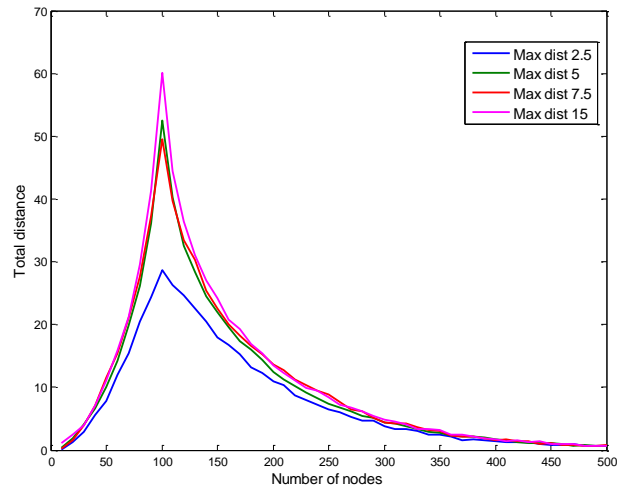


Figure 4 Total distance moved by nodes for coverage improvement

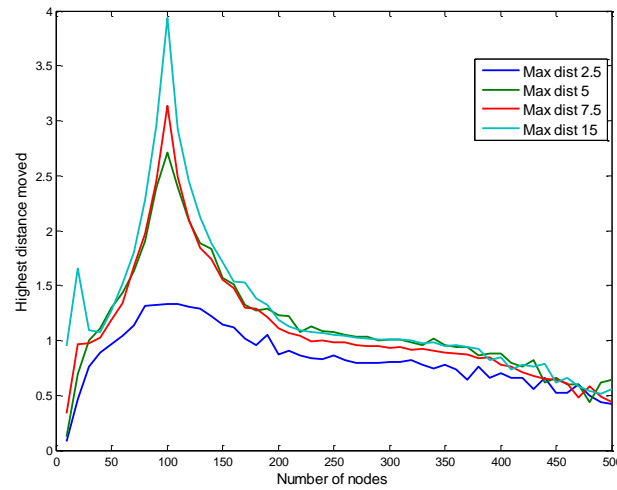


Figure 5 Highest distance moved by a node

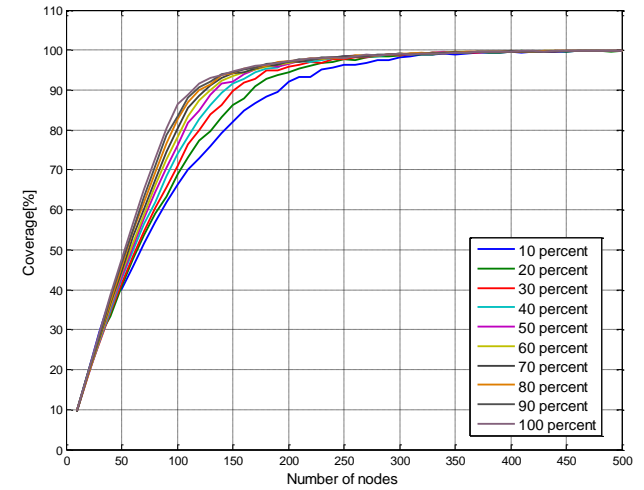


Figure 6 Coverage percentage with constrained mobility distance 2.5 units

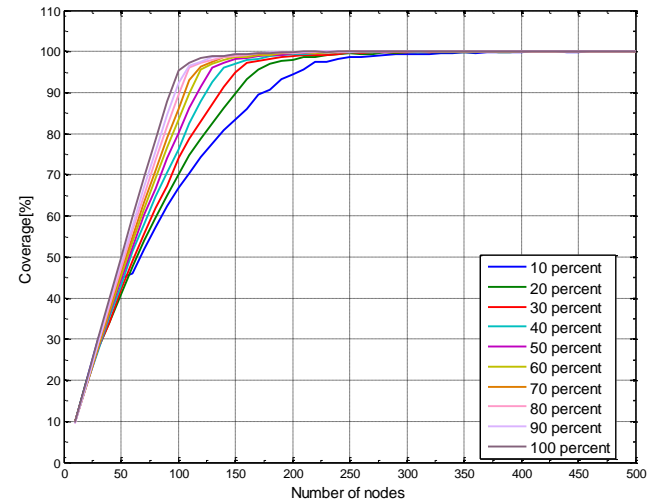


Figure 7 Coverage percentage with constrained mobility distance 5 units

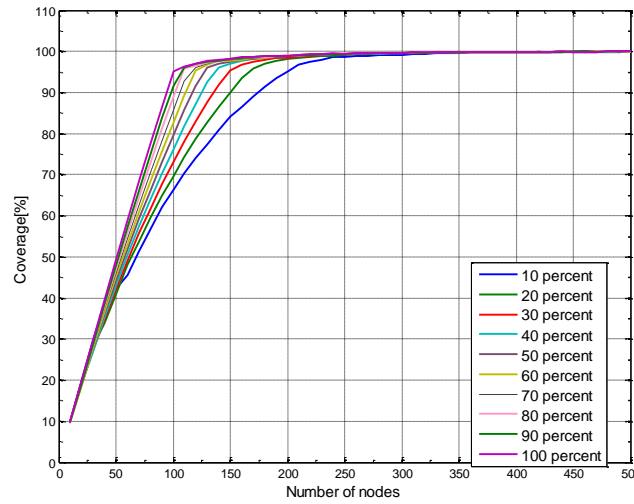


Figure 8 Coverage percentage with constrained mobility distance 7.5 units

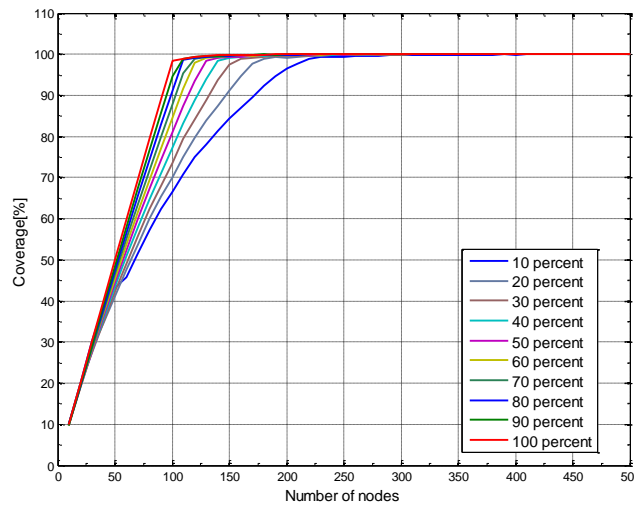


Figure 9 Coverage percentage with constrained mobility distance 15 units

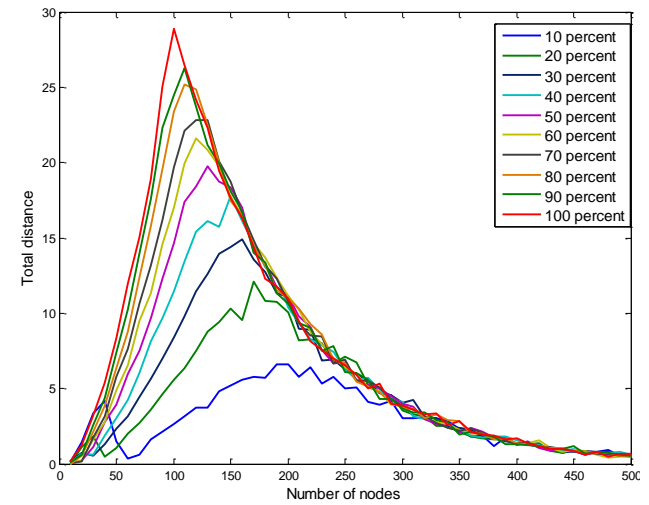


Figure 10 Total distance moved by the nodes for constrained mobility (2.5 units) and varying percent of mobile nodes with corresponding coverage shown in Fig 6.

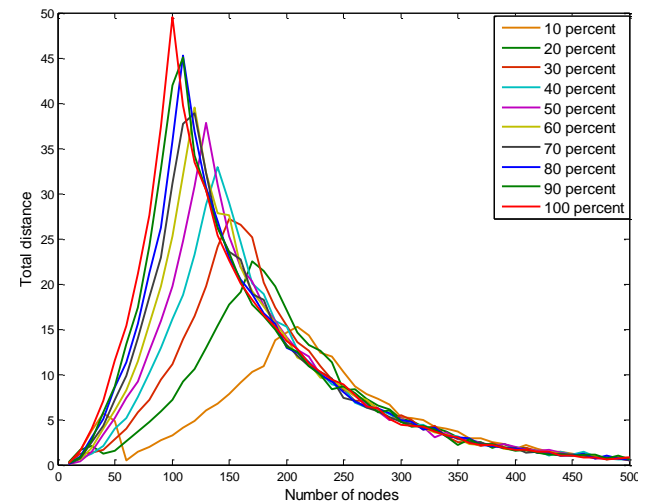


Figure 11 Total distance moved by nodes for constrained mobility (5 units) and varying percent of mobile nodes with corresponding coverage shown in Fig 7.

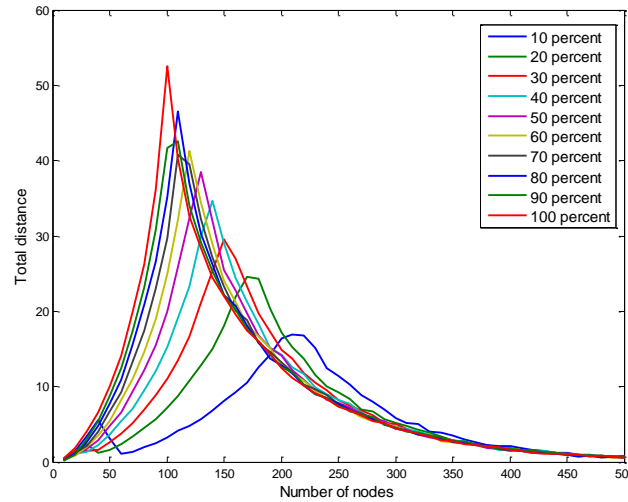


Figure 12 Total distance moved by the nodes for constrained mobility (7.5units) and varying percent of mobile nodes with corresponding coverage shown in Fig 8.

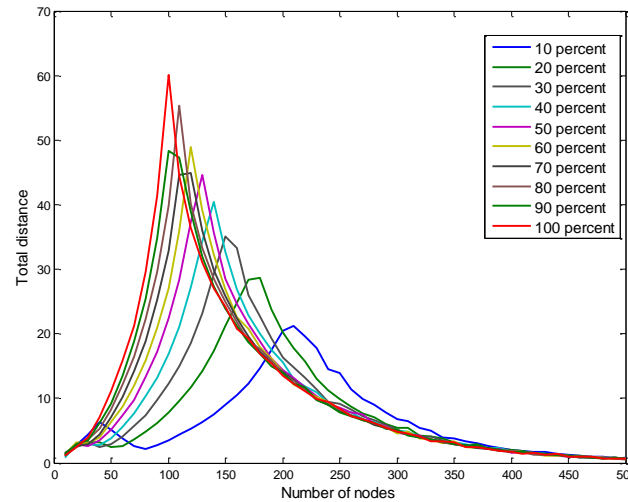


Figure 13 Total distance moved by the nodes for constrained mobility (15 units) and varying percent of mobile nodes with corresponding coverage shown in Fig 9.

Coefficients for a function between coverage attained; number of total nodes, number of mobile nodes, maximum permissible distance to move and the distance moved by nodes has been derived using linear regression as per Eq 2 and 3. Considering total number of nodes, N_t , number of mobile nodes, N_m , maximum permissible distance movable

by nodes, D_{per} , maximum distance moved by nodes D_m and the corresponding total network coverage N_c , the relation becomes:

$$N_c = 6.400 + 0.1766N_t + 0.211N_m + 2.3D_{per} \quad (2)$$

$$D_m = 5 - 0.0432N_t + 0.0177N_m + 1.913D_{per} \quad (3)$$

5. Conclusions

The results present a precise relation between the various parameters for a particular deployment condition with respect to the coverage obtained. The results can be used as a yardstick for real deployments based on the resources available and the constraints applicable (total number of nodes, proportion of mobile nodes, highest mobility distance and the number of mobile nodes available). This work can be extended to attain an overall network yardstick which takes into account all the parameters related with the deployment of a practical sensor network for attaining a desired performance, based on the resources available.

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7. Author Biographies

Prateek Mathur is currently enrolled as a PhD student at Center for TeleInfrastruktur (CTIF) at Aalborg University (AAU), Denmark. He received his M.Sc degree from University of Bradford, U.K. and Bachelor of Engineering from University of Pune, India in 2009 and 2008 respectively. His research focus is on node mobility for studying deployment, clustering and data aggregation aspects of wireless sensor networks.

Rasmus Hjorth Nielsen is an assistant professor at Center for TeleInfrastruktur (CTIF) at Aalborg University (AAU), Denmark and is currently working as a senior researcher at CTIF-USA, Princeton, USA. He received his M.Sc. and Ph.D. in electrical engineering from Aalborg University in 2005 and 2009 respectively. He has been working on a number of EU- and industrial funded projects primarily within the field of next generation networks where his focus is currently security and performance optimization. He has a strong background in operational research and optimization in general and has applied this as a consultant within planning of large-scale networks. His research interests include IoT, WSNs, virtualization and other topics related to next generation converged wired and wireless networks.

Neeli R. Prasad Ph.D., IEEE Senior Member, Head of research at the Center for TeleInfrastruktur (CTIF) at Aalborg University and Director of CTIF-USA, Princeton, USA. She has over 14 years of management and research experience both in industry and academia. She has gained a large and strong experience into the project coordination of EU-funded and Industrial research projects. Her current research interests are in the area of QoL, SON, IoT, Identity Management, mobility, network management and monitoring; practical radio resource management; cognitive learning capabilities and modeling; Security, Privacy and Trust. Experience in other fields includes physical layer techniques, policy based management, short range communications. Her publications range from top journals, international conferences and chapters in books. She has also co-edited and co-authored two books and has over 50 peer reviewed papers in international journals and conferences. She is also very active in several conferences as chair and as program committee member.

Ramjee Prasad has been holding the Professorial Chair of Wireless Information and Multimedia Communications at Aalborg University, Denmark (AAU) since June 1999. Since 2004 he is the Founding Director of the Center for TeleInfrastruktur (CTIF), established as large multi-area research center at the premises of Aalborg University. Ramjee Prasad is a Fellow of IEEE, the IET and IETE is a worldwide established scientist, which has given fundamental contributions towards development of wireless communications. He achieved fundamental results towards the development of CDMA and OFDM, taking the leading role by being the first in the world to publish books in the subjects of CDMA (1996) and OFDM (1999). He is the recipient of many international

academic, industrial and governmental awards and distinctions of which the most recently is the cross of the order of chivalry (Ridderkorset af Dannebrogordenen) from the Danish Queen due internationalization of top-class telecommunication research and education. Ramjee Prasad has a long path of achievements until to date and a rich experience in the academic, managerial, research, and business spheres of the mobile and wireless communication area. Prof. Prasad has authored or co-authored more than 700 high cited scientific articles published in peer-reviewed conference proceedings and international journals. Since 1999, he has published 8 monographs, 22 books, 18 book chapters and more than 70 and 190 articles in journals and conference proceedings. Furthermore he has 15 patents within his research areas.