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Monday, Jun 29

09:30 - 10:30

O: Opening talk

Cognitive Networks: Throughput, Delay Bounds and Routing Issues
Luigi Fratta (Politecnico di Milano, Italy)
Cognitive Radio Networks (CRNs) are composed of frequency-agile radio devices that allow licensed (primary) and unlicensed (secondary) users to coexist, where secondary users opportunistically access channels without interfering with the operation of primary ones. From the perspective of secondary users, spectrum availability is a time varying network resource over which multi-hop end-to-end connections must be maintained. Analytical bounds on throughput and transmission delay of secondary users under different assumptions on secondary and primary users traffic statistics in a single channel scenario will be presented. Then it will be discussed the problem of routing secondary user flows in a CRN with the aim of characterizing optimal sequences of routes over which a secondary flow is maintained. The optimality is defined according to a novel metric that considers the maintenance cost of a route as channels and/or links must be switched due to the primary user activity. Different from the traditional routing problem, the proposed approach considers subsequent path selections. The problem can be formulated as an integer programming optimization model and shown to be of polynomial time complexity in case of full knowledge of primary user activity. The use of heuristic algorithms, to solve the minimum maintenance cost routing problem when information on primary user activity is not complete, will be discussed. Some numerical results will allow to assess the optimality gap of a proposed heuristic routing algorithm.

11:00 - 12:30

T1: Technical session 1

Chair: Jean-Marc Robert (Ecole de Technologie Supérieure, Canada)

3DLS: Density-Driven Data Location Service for Mobile Ad-Hoc Networks (Workshop Talk)
Roy Friedman (Technion, Israel)
Finding data items is one of the most basic services of any distributed system. It is particular challenging in ad-hoc networks, due to their inherent decentralized nature and lack of infrastructure. A data location service (DLS) provides this capability. This paper presents 3DLS, a novel density driven data location service. 3DLS is based on performing biased walks over a density based virtual topography. 3DLS also includes an autonomic dynamic configuration mechanism for adapting the lengths of the walks, in order to ensure good performance in varying circumstances and loads. This is without any explicit knowledge of the network characteristics, such as size, mobility speed, etc. Moreover, 3DLS does not rely on geographical knowledge, its decisions are based only on local information, it does not invoke multi-hop routing, and it avoids flooding the network. The paper includes a detailed performance study of 3DLS, carried by simulations, which compares 3DLS to other known approaches. The simulations results validate the viability of 3DLS. Joint work with Noam Mori (Technion, IL).

CORP: Cooperative Rateless code Protocol for Vehicular Content Dissemination
Pasquale Cataldi (University of California, Los Angeles, USA); Andrea Tomatis (Hitachi Europe, France); Gianluca Grilli (UCLA, USA); Mario Gerla (University of California at Los Angeles, USA)
Data dissemination in vehicular networks has been a challenge due to the unpredictable network dynamics and to the channel unreliability. In fact, conventional approaches that use TCP or UDP do not perform well and cannot consistently guarantee reliable communications. A potential solution to these problems involves using error-correcting codes to make UDP transmissions reliable. However, it is also important to note that, due to the dynamic scenario, connections among nodes are usually limited to few seconds. Therefore, in a communication between two nodes, the delay between node discovery and data exchange should be minimal. In this paper we present VDRP, a new protocol that exploits the reliability of the rateless approach while performing fast and efficient dissemination through cooperating nodes within the network. The use of rateless codes and unicast connections makes the reconciliation problem a task that can be solved in an efficient and simple way, thus minimizing the delay between node discovery and data transmission. Results from simulations reveal that performance improves as more and more nodes cooperate. In sum, VDRP yields important improvements in the speed of dissemination when compared to standard rateless approaches.
pp. 1-7

Random Access Wireless Networks with Controlled Mobility
Guner Celik (MIT, USA); Eytan Modiano (MIT, USA)
This paper considers wireless networks where messages arriving randomly (in time and space) are collected by a mobile receiver. The messages are transmitted to the mobile receiver according to a random access scheme and the receiver dynamically adjusts its position in order to receive these messages in minimum time. We study utilizing a combination of wireless transmission and controlled mobility to improve the delay performance in such networks. In particular, we characterize the tradeoff between wireless transmission and physical movement of the mobile receiver.We derive a lower bound for the delay in the system and show how it is affected by different communication parameters. We show that the combination of mobility and wireless transmission results in a significant improvement in delay as compared to a system where wireless transmission is not used.
pp. 8-14

Topology Design and Control: A Game-Theoretic Perspective (Workshop Talk)
Amir Nahir (Technion, Israel)

We study the performance of non-cooperative networks in light of three major topology design and control considerations, namely the price of establishing a link, path delay, and path proneness to congestion or interference, the latter being modeled through the "relaying extent" of the nodes. We analyze these considerations and the tradeoffs between them from a game theoretic perspective, where each network element attempts to optimize its individual performance. We show that for all considered cases but one, the existence of a Nash equilibrium point is guaranteed. In addition, we demonstrate that the price of anarchy, i.e., the performance penalty incurred by non-cooperative behavior, may be prohibitively large; yet, we also show that such games usually admit at least one Nash equilibrium that is system-wide optimal, i.e., their price of stability is 1. This finding suggests that a major improvement can be achieved by providing a central ("social") agent with the ability to impose the initial configuration on the system. Joint work with Ariel Orda (Technion, IL), Ari Fruend (IBM Research, Israel).

14:00 - 15:30

T2: Technical session 2

Chair: Eytan Modiano (MIT, USA)

Preventing Layer-3 Wormhole Attacks in Ad-hoc Networks with Multipath DSR
Luis Fernando Garcia (École de Technologie Supérieure, Canada); Jean-Marc Robert (Ecole de Technologie Supérieure, Canada)
Wormhole attacks in ad-hoc networks have been attracting much attention over the years. They consist in two malicious nodes tunneling traffic from one end of the network to the other. Several approaches are proposed to detect these attacks in single path routing schemes. Unfortunately, only few solutions deal with multipath routing schemes. A new approach detecting wormhole attacks is presented in this paper. The Witness Integration Multipath protocol uses the information provided by a multipath routing protocol based on DSR and finds suspicious patterns related to wormhole attacks without any hardware requirement or protocol modification.
pp. 15-20

Cross-Layer Hybrid FEC/ARQ Reliable Multicast with Adaptive Modulation and Coding in Broadband Wireless Networks (Workshop Talk)
Guy Grebla (Technion-Israel Institute of Technology, Israel)
In this paper we define and address a new problem that arises when a base station in a broadband wireless network wishes to multicast information to a large group of nodes and to guarantee some level of reliability using Application layer FEC codes. Every data block to be multicast is translated into a sequence of K + n packets, from which every receiver must receive at least K in order to correctly decode the block. The new problem is to determine which PHY layer MCS (Modulation and Coding Scheme) the base station should use for each packet. We present several variants of this problem, which differ in the number of ARQ (Automatic Repeat reQuest) rounds during which the delivery of a data block must be completed. Most of these variants are shown to be NP-hard. However, we present optimal solutions for practical instances, where the number of MCSs is small, and efficient approximations and heuristics for the general case of each variant. Joint work with Reuven Cohen (Technion, IL) and Liran Katzir (Technion, IL)

Extrapolation-based and QoS-aware Real-Time Communication in Wireless Mobile
Adnan Agbaria (IBM Haifa Research Lab, Israel); Gidon Gershinsky (IBM Haifa Research Lab, Israel); Nir Naaman (IBM Haifa Research Lab, Israel); Konstantin Shagin (IBM Research Lab in Haifa, Israel)
In mobile ad hoc networks (MANETs), it is increasingly important to devote attention to real-time and quality of service (QoS) issues. We present here a novel extrapolation-based and QoS-aware technology for providing soft real-time services in MANETs. The proposed technology combines elements of proactive and location-based techniques. Each node maintains a global view, which is periodically updated through state exchange among all the nodes. At any time, a node is able to extrapolate the location of a given node based on its velocity vector. Resource management, dynamic scheduling, velocity-based extrapolation, and multipath search techniques are employed to meet the real-time and QoS requirements despite network contention and frequent topology changes. We demonstrate this technology by presenting a real-time and QoS routing protocol. We evaluate the performance of the protocol and compare it to the performance of other well-known routing protocols.
pp. 21-26

Cross-Layer On-Demand Routing Algorithms for Multi-Hop Wireless CSMA/CA Networks (Workshop Talk)
Izhak Rubin (University of California at Los Angeles, USA)
We investigate the impact of combined multi-rate and routing operations in multi-hop wireless ad hoc networks in which nodes employ 802.11-based CSMA/CA MAC protocols. To measure the ability of the network to transport traffic in a throughput effective manner, we employ the link-flow transport throughput capacity measure as a key routing metric. The latter measure considers multi-rate operations as well as instantaneous topological, loading and capacity availability conditions. We develop on-demand cross layer schemes that employ these transport throughput metrics for route discovery purposes. We compare the performance behavior of our schemes with that exhibited by those that do not use the link-flow transport throughput capacity function as a routing metric. We demonstrate the performance effectiveness of these schemes by evaluating three distinct network scenarios. Joint work with Ju-Lan Hsu (UCLA, US).

Tuesday, Jun 30

08:30 - 09:30

K: Keynote

Vehicular Urban Sensing: Dissemination and Retrieval
Mario Gerla (University of California at Los Angeles, USA)
There has been growing interest in vehicle to vehicle communications for a broad range of applications ranging from safe driving to content distribution, advertising, commerce and games. One emerging application is urban sensing. Vehicles monitor the environment, classify the events, e.g., license plates, pollution readings, etc. and exchange metadata with neighbors in a peer-to-peer fashion, creating a distributed index from which mobile users can extract different views. For instance, the Department of Transportation captures traffic statistics; the Department of Health monitors pollutants, and; Law Enforcement Agents investigate crimes. Mobile, vehicular sensing differs significantly from conventional wireless sensing. Vehicles have no strict limits on battery life, processing power and storage capabilities. Moreover they can generate enormous volumes of data, making conventional sensor data collection inadequate. In this talk we first review popular V2V applications and then introduce MobEyes, a middleware solution that diffuses data summaries to create a distributed index of the sensed data. We discuss the challenges of designing and maintain such a system, from information dissemination to harvesting, routing and privacy.

10:00 - 11:30

T3: Technical session 3

Chair: Nir Naaman (IBM Haifa Research Lab, Israel)

TDCS: A New Mechanism for Automatic Channel Assignment for Independent IEEE 802.11 Networks

Marcel Silva (Universidade Federal do Rio de Janeiro, Brazil); Jose F. de Rezende (Federal University of Rio de Janeiro, Brazil)

In the last few years, IEEE 802.11 applications has experienced a significant growth. This expansion creates scenarios where distinct administrators manage wireless networks. These scenarios lack of a unique authority to perform an adequate channel allocation that minimizes the performance degradation generated by medium access sharing and co-channel interference. This work proposes a new dynamic channel selection mechanism that focuses on the restrictions imposed by scenarios with independent IEEE 802.11 networks and adapts faster to the interference pattern variations. Besides, the performance of the new mechanism is evaluated and compared to others through simulations.

pp. 27-33

Throughput-Capacity and Bit-per-Joule Performance of IEEE 802.11 Based Wireless Mesh Networks

Rima Khalaf (University of California, Los Angeles, USA); Izhak Rubin (University of California at Los Angeles, USA)

Energy consumption is of utmost importance in wireless mesh networks where nodes are battery operated and have limited power resources. In this paper, we develop an analytical model to estimate the throughput-capacity of a wireless mesh network and use this model to study the network's bit-per-joule performance. We assume that each node uses an IEEE 802.11 based software controlled radio whose modulation/coding scheme and rate can be dynamically selected. A topology synthesis algorithm is used to elect nodes to act as access points as well as backbone nodes. The latter form a mesh backbone network infrastructure. We present an algorithm that is used to analytically calculate an approximation of the throughput capacity performance of the network. We use this algorithm to examine the performance efficiency of the network, expressed in terms of the throughput rate per unit energy consumed under the joint setting of nodal transmit power and data rate levels. Our results show that when traffic is uniformly distributed across the area of operations, increasing the nodal transmit power levels, as well as the data rates, tend often to enhance the bit-per-joule performance of the system. We also examine the impact of the selection of the transmit data rate and power levels used in conducting the topology synthesis of the backbone network.

pp. 34-41

RI-MAC: A Receiver Initiated Asynchronous Duty Cycle MAC Protocol for Dynamic Traffic Loads in Wireless Sensor Networks (Workshop Talk)

Omer Gurewitz (Ben Gurion University, Israel)

The problem of idle listening is one of the most significant sources of energy consumption in wireless sensor nodes, and many techniques have been proposed based on duty cycling to reduce this cost. In this paper, we present a new asynchronous duty cycle MAC protocol, called Receiver-Initiated MAC (RI-MAC), that uses receiver-initiated data transmission in order to efficiently and effectively operate over a wide range of traffic loads. RI-MAC attempts to minimize the time a sender and its intended receiver occupy the wireless medium to find a rendezvous time for exchanging data, while still decoupling the sender and receiver's duty cycle schedules. We show the performance of RI-MAC through detailed ns-2 simulation and through measurements of an implementation in TinyOS in a testbed of MICAz motes. Compared to the prior asynchronous duty cycling approach of X-MAC, RI-MAC achieves higher throughput, packet delivery ratio, and power efficiency under a wide range of traffic loads. Especially when there are contending flows, such as bursty traffic or transmissions from hidden nodes, RI-MAC significantly improves throughput and packet delivery ratio. Even under light traffic load for which X-MAC is optimized, RI-MAC achieves the same high performance in terms of packet delivery ratio and latency while maintaining comparable power efficiency. Joint work with Yanjun Sun (Rice University, US and David B. Johnson (Rice University, US)

MAC for Networks with Multipacket Reception Capability and Spatially Distributed Nodes (Workshop Talk)

Gil Zussman (Columbia University, USA)

The physical layer of future wireless networks will be based on novel radio technologies such as UWB and MIMO. One of the important capabilities of such technologies is the ability to capture a few packets simultaneously. This capability has the potential to improve the performance of the MAC layer. However, we show that in networks with spatially distributed nodes, reusing backoff mechanisms originally designed for narrow-band systems (e.g. CSMA/CA) is inefficient. It is well known that when networks with spatially distributed nodes operate with such MAC protocols, the channel may be captured by nodes that are near the destination, leading to unfairness. We show that when the physical layer enables multipacket reception, the negative implications of reusing the legacy protocols include not only such unfairness but also a significant throughput reduction. We present alternative backoff mechanisms and evaluate their performance via Markovian analysis and simulation. We show that our alternative backoff mechanisms can improve both overall throughput and fairness. Joint work with Gunar D. Celik (MIT, US), Wajahat F. Khan (MIT, US), and Eytan Modiano (MIT, US).

12:00 - 13:30

T4: Technical session 4

Chair: Erol Gelenbe (Imperial College London, United Kingdom)

Maximum-Lifetime Routing: System Optimization & Game-Theoretic Perspectives (Workshop Talk)

Joseph (Seffi) Naor (Technion, Israel)

Routing traffic so as to maximize the lifetime of a transmission is a major problem in wireless networks. We address a two-way multicast problem, where a root wishes to transmit data to a subset of nodes, as well as receive data from them. In addition, we consider the anycast problem, wherethere is a subset of nodes that wish to communicate with each other. We consider both a per-hop multi-recipients environment, where over each hop, the transmission is received by all nodes within range, and a per-hop single-recipient environment, where over each hop the transmission is received by a single recipient. For both environments, our work consists of two parts. In the first part we focus on system optimization perspectives of the lifetime maximization problem, while in the second part we investigate the game-theoretic perspective of the respective problems. We first note that, for the per-hop multi-recipients environment, an optimal solution can be computed in polynomial time. Nevertheless, for the per-hop single-recipient environment, we observe that computing an optimal solution is NP-hard. Accordingly, we provide a polynomial time algorithm that finds a 2-approximate solution for the case of uniform transmission power levels. For different transmission power levels, we provide an O(log2 n) approximation algorithm for the general problem, and an O(log n) approximation algorithm for the special case where the set of terminals equals the set of all nodes, whose size equals n. For each environment, we consider the corresponding noncooperative game scenario, and prove that by following the natural game course users converge to a Nash equilibrium. For the per-hop multi-recipients environment, we show that if the players join the game sequentially, the Nash equilibrium is (networkwide) optimal. For the per-hop single-recipient environment, we show that the price of anarchy is unbounded. On the other hand, we show that for both environments, the price of stability, where the best Nash equilibrium is considered, is 1; hence, optimal (networkwide) performance can be achieved if the initial configuration can be imposed on the players. Joint work with Liane Lewin-Eytan (Technion, IL) and Ariel Orda (Technion, IL)

Scalable Communication Cost Reduction: The Chord Case

Konstantinos Oikonomou (Ionian University, Greece); Spyros Sioutas (Ionian University, Greece); Ioannis Stavrakakis (National and Kapodistrian University of Athens, Greece)

In peer-to-peer (P2P) network system design the dominating focus is on efficient service discovery schemes, most frequently assuming permanent (or longterm stationary) positions for service facilities, thus neglecting communication costs due to the actual locations of the facilities. Since the problemof communication cost minimization is a large optimization problem (NP-hard) and requires global information (i.e., not scalable), in this paper the service migration philosophy is adopted which permits service facility movements and yields smaller communication cost in a scalable manner (i.e., based on local information). Service migration is incorporated in the Chord P2P system, imposing certain changes (e.g., the extension of the service discovery scheme of Chord) and introducing an extra system overhead (i.e., update messages) for the efficient operation of the (enhanced) system. As it is demonstrated here using simulation results, the communication cost corresponding to the extra system overhead is significantly small and more than enough compensated by the communication cost reduction due to the introduction of service migration. As long as the network remains unchanged, the former communication cost is paid only once while the latter communication cost reduction is permanent.

pp. 42-47

A Novel Routing Algorithm Based on Chord for Hybrid Wireless Ad-hoc Networks

Jing Cao (Beihang University, P.R. China); Wei Wu (State Key Laboratory of Virtual Reality Technology and Systems, P.R. China)

The scale of network and bandwidth of link have been limited by current routing technologies in hybrid wireless Ad-hoc networks, so we present a new routing algorithm. In the routing algorithm, the routing information is treated as a resource, and it can be stored and searched in a distributed way with Chord. The routing of data packet prefers to forward by infrastructure. In comparison with OLSR, the algorithm can not only improve the network throughput by average 25%, but also save the delay of End-to-End by average 30%. And with the increasing of network scale, the benefit will be more significant.

pp. 48-53

Self-stabilizing and self-organizing mobile networks (Workshop Talk)

Shlomi Dolev (Ben-Gurion University, Israel)

Self-stabilization ([Dij74], [Dolev00]) is an important property of any dynamic long-lived system. Self-stabilizing systems may start operating in any arbitrary state, and can therefore recover following a temporary violation of the assumption made by the system designer. Mobile ad-hoc networks are very dynamic in nature and must cope with unreliable and sometimes unpredictable environments. Thus the design of self-stabilizing mobile and ad-hoc networks is of great importance. Self-stabilizing networks are self-organizing if they start to operate as they should in sub-linear time. We overview several recent works demonstrating several directions for creating adaptive infrastructures and abstractions; namely self-stabilizing and self-organizing infrastructures. These infrastructures fit the mobile ad-hoc network characteristic.

14:30 - 16:00

T5: Technical session 5

Chair: Roy Friedman (Technion, Israel)

Content-Based Routing Using Subpart Orthogonal Codes

Christine Jardak (RWTH Aachen university, Germany); Janne Riihijärvi (RWTH Aachen University, Germany); Petri Mähönen (RWTH Aachen University, Germany)

We study the use of orthogonal codes as alternative to Bloom filters in content-based routing. In particular we explore the trade-off between centralized solutions using regular orthogonal codes and generating codes locally by hashing. We demonstrate that introduction of \emph{subpart orthogonal codes} allows distributed operation while leading to shorter key lengths than Bloom filters with the same probability of data localization. We study the performance of sub-part orthogonal codes by both analytical means and in a simulation environment. Results show that the use of sub-part orthogonal codes reduces overhead without sacrificing performance in both tree and grid topologies.

pp. 54-59

Travel delays in wireless networks (Workshop Talk)

Erol Gelenbe (Imperial College London, United Kingdom)

We consider a wireless network in which packets are forwarded opportunistically from the source towards the destination, without accurate knowledge of the direction that they should take. A Brownian motion model that includes the effect of packet losses, and subsequent retransmission after a time-out, is used to compute the average travel time of the packet. The results indicate that the average travel time is always finite provided that a time-out is used, and that there is an element of randomness in the manner in which successive nodes are being chosen. We show that the average packet travel time can be minimized by a judicious choice of the time-out, and its optimum value in turn depends on other system parameters such as packet-loss probabilities. We present simulations that illustrate the analytical results.

Random walks techniques for wireless networks (Workshop Talk)

Chen Avin (Ben-Gurion University of the Negev, Israel)

In recent years random-walk-based algorithms have been proposed for a variety of networking tasks. These proposals include searching, routing, self-stabilization, and query processing in wireless networks, peer-to-peer networks and other distributed systems. This approach is gaining popularity since random walks present locality, simplicity, low-overhead and inherent robustness to structural changes. Two properties of the random walk on graphs are essential to determine the efficiency of this approach: cover time (the expected time to visit all nodes) and mixing time (in regular graphs, the time to sample a node uniformly). In this talk I will present some of the work on the topic I was involved in, emphasizing results related to applications for wireless networks.

"Not All At Once!" - A Generic Scheme for Estimating the Number of Affected Nodes (Workshop Talk)

Alexander Landau (Technion, Israel)

In this talk, we present a generic scheme, called NATO!, for estimating the size of a group of nodes affected by the same event in a large-scale network, such as a grid, a sensor network or a wireless broadband access network, while receiving only a small number of feedback messages from this group. Using the proposed scheme, a centralized gateway analyzes the transmission times of these feedback messages, defines a likelihood function for them, and then uses the Newton-Raphson method to find the number of affected nodes for which this function is maximized. We present complete mathematical analysis for the precision of the proposed algorithm and provide tight upper and lower bounds for the estimation error. We then show how to use NATO! in order to improve the performance of large-scale partially reliable multicast streaming in a broadcast wireless network. Joint work with Reuven Cohen (Technion, IL).

16:30 - 18:00

T6: Technical session 6

Chair: Gil Zussman (Columbia University, USA)

On the Exploitation of CDF based Wireless Scheduling (Workshop Talk)

Anat Bremler-Barr (Interdisciplinary Center Herzliya, Israel)

Channel-aware scheduling strategies - such as the CDF Scheduler (CS) algorithm for the CDMA/HDR systems - provide an effective mechanism for utilizing the channel data rate for improving throughput performance in wireless data networks by exploiting channel fluctuations. A highly desired property of such a scheduling strategy is that its algorithm will be stable, in the sense that no user has incentive "cheating" the algorithm in order to increase his/her channel share (on the account of others). We present a scheme by which coordination allows a group of users to gain permanent increase in both their time slot share and in their throughput, on the expense of others, by misreporting their rates. We show that for large populations consisting of regular and coordinated users in equal numbers, the ratio of allocated time slots between a coordinated user and a regular one converges to e-1≈1.7. Our scheme targets the very fundamental principle of CS (as opposed to just attacking implementation aspects), which bases its scheduling decisions on the Cumulative Distribution Function (CDF) of the channel rates reported by users. Our scheme works both for the continuous channel spectrum and the discrete channel spectrum versions of the problem. Joint work with Udi Ben-Porat (Tel-Aviv University, IL)and Hanoch Levy (Tel-Aviv University, IL)

Toward Optimal Utilization of Shared Random Access Channels (Workshop Talk)

Danny Raz (Technion, Israel)

We consider a multipacket reception channel shared by several communication applications. This is the case, for example, in a single radio mesh network where neighboring cells use the same radio channel. In such scenarios, unlike the common multiple access model, several transmissions may succeed simultaneously, depending on the actual locations of the sending and receiving stations, and thus channel utilization may be greater than 1. Our goal is to derive a decentralized access control mechanism that maximizes the channel utilization, while taking into account fairness among the different users. We focus on a simple case where each user can adjust a single parameter that determines its transmission probability in any time slot, and develop such a protocol for the general problem, where users are distributed arbitrarily, based on strong motivation which is derived from analytical bounds for homogeneous interferences. We further show, using extensive simulations, that this protocol achieves a high utilization of radio resources compared to any other protocol (not necessary based on a simple parameter), while maintaining fairness between all users. Joint work with Seffi Naor (Technion, IL) and Gabriel Scalosub (University of Toronto, CA)

Improved Approximation Algorithms for Relay Placement (Workshop Talk)

Alon Efrat (University of Arizona, USA)

In the relay placement problem the input is a set of sensors and a number $r \geq 1$, the communication range of a relay. In the one-tier version of the problem the objective is to place a minimum number of relays so that between every pair of sensors there is a path through sensors and/or relays such that the consecutive vertices of the path are within distance r if both vertices are relays and within distance 1 otherwise. The two-tier version adds the restrictions that the path must go through relays, and not through sensors. We present a 3.11-approximation algorithm for the one-tier version and a PTAS for the two-tier version. We also show that the one-tier version admits no PTAS, assuming $P \neq NP$. Joint work with Sándor P. Fekete (Braunschweig University of Technology, DE), Poornananda R. Gaddehosur (The University of Arizona, US), Joseph S. B. Mitchell (Stony Brook University, US), Valentin Polishchuk (Helsinki Institute for Information Technology HIIT, FI), and Jukka Suomela (Helsinki Institute for Information Technology HIIT, FI)