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Program

	Monday, June 10	Tuesday, June 11	Wednesday, June 12	Thursday, June 13
9:00 - 10:30	W1: *STP-CPS workshop* W2: *IAUV workshop*			
10:30 - 11:00				A5: *Networked Robotics*
11:00 - 12:30		C1: *Best Paper Award Session*		B5: *Edge/Fog Computing*
12:30 - 13:40				
13:40 - 14:00		A1: *Activity Recognition* B1: *Concurrent and Cooperative Communication*	A3: *Wearable/Cyber-Physical Systems* B3: *Security & Privacy*	
14:00 - 15:40	W3: *MLCN-IoT workshop* W4: *CyberEdge workshop*			
15:40 - 16:00				
16:00 - 17:30		A2: *Localization and Tracking* B2: *Spectrum*	A4: *Energy Efficient Systems* B4: *Multimedia Analytics and Applications*	
17:30 - 18:00				
18:00 - 19:00		PD: *Posters/Demos*		

Monday, June 10

Monday, June 10 9:00 - 12:30

W1: STP-CPS workshop

MSNET-Blockchain: A New Framework for Securing Mobile Satellite Communication Network

Ming Feng and Hao Xu (University of Nevada, Reno, USA)

In this paper, the security problem for mobile satellite communication networks (MSNET) has been investigated. With the rapidly growth of communication needs, mobile satellite systems represent a significant solution to provide high-quality communication services to mobile users in under-populated regions, in emergency areas, on planes, trains and ships. However, lacking an effective framework to secure mobile satellite communication networks seriously limited the practicality of satellite services. Therefore, a new security framework have been developed in this paper to address the security challenges in mobile satellite communication network. Firstly, the mobile satellite communication networks have been formulated as delay tolerance network (DTN). Then, the blockchain technique has been adopted and used in two aspects, i.e. 1) integrating with DTN structure to secure the data communication, 2) combing with the practical satellite constellation

intelligence gained by them provide us convenience, they border on intrusion as they feed into powerful analytics engines to convert large volumes of personal data, to actionable intelligence. This data can reveal our personal habits and lifestyles. While it is a huge convenience to have these smart devices make recommendations based on data patterns, it becomes a threat to privacy once the insights gained by this data crosses a threshold. We hypothesize that it is possible to reverse engineer privacy intrusion by learning through sensors that are in the user's context and those he/she interacts with. There are numerous facets to privacy; personal, localization, financial, social, genealogical, emotional and others. We analyze various indicators and build a model on the training dataset to gain insights into personal and localization privacy. We then use the validation dataset to assess the prediction accuracy of the model. We use the insights from the model to arrive at a privacy intrusion threat score for individuals.
pp. 26-34

Non-Intrusive Deployment of Blockchain in Establishing Cyber-Infrastructure for Smart City

Adeel A Malik (University of Texas at El Paso, USA); Deepak K Tosh (University of Texas, El Paso, USA); Uttam Ghosh (Vanderbilt University, USA)

Smart city architecture can be exceptionally intricate due to the extremely large variety of devices and the implemented technologies. Deploying such infrastructure is very burdensome and is exposed to several unique challenges (e.g. infrastructure, deployment, security, and privacy). Blockchain technology can provide a secure and resilient smart city infrastructure. Blockchain offers a ledger service over a distributed network where the peers or devices on the blockchain network maintain a set of ordered transactions and their states in the form of chained blocks. Each block has its own cryptographic hash and any change in the block data changes the hash, thus making the state of the block invalid and the blockchain tamperproof. In this paper, we have proposed a decentralized architecture for a smart city infrastructure using blockchain technology and a systematic methodology to address the infrastructural challenges concerning smart city deployment. Finally, we implement and evaluate using an automation module and achieve approximately 82% time reduction compared with traditional deployment approach.
pp. 35-40

An Improved Communications in Cyber Physical System Architecture, Protocols and Applications

ES Madhan (Anna University, India); Uttam Ghosh (Vanderbilt University, USA); Deepak K Tosh (University of Texas, El Paso, USA); Mandal K, E Murali and Soumalya Ghosh (Galgotias University, India)

In recent trends, Cyber Physical Systems (CPS) and Internet of Things interpret an evolution of computerized integration connectivity. The specific research challenges in CPS as security, privacy, data analytics, participate sensing, smart decision making. In additional, Wireless Sensor Networks (WSN) challenges which includes secure architecture, standard protocols, energy efficiency and quality of services. In this paper, we discuss from a CPS viewpoint of architectures, protocols and applications. Moreover, an improved proposed Cyber Physical Systems which used to apply in many domain applications. Examples include infrastructure, transportation, manufacture process and defense and so on.
pp. 41-46

W2: IAUV workshop

Formation control of a mono-operated UAV fleet through ad-hoc communications: a Q-learning approach

Nicola Roberto Zema (LRI - Paris 11, France); Dominique Quadri (LRI, University Paris-Sud, Paris-Saclay, France); Steven Martin (Paris-Sud University, France); Omar Shrit (University of Paris Sud, France)

In this paper, an innovative approach based on a Q-learning algorithm to allow a single operator to control a fleet of Unmanned Aerial Vehicles (UAVs) is presented. To follow an independently-controlled UAV (the leader), all the other UAVs (the followers) use only the radio signal strength values received during wireless ad-hoc communications among themselves, without the need for any infrastructure, any localization technique or any additional device. By applying the proposed behavior-based control scheme in real-time, the fleet formation can be perfectly maintained. The solution has been implemented through the definition of a new protocol and has been tested using ns-3. Experiments highlight the efficiency and effectiveness of the proposed method.\\

pp. 47-52

A Solution for Dynamic Spectrum Management in Mission-Critical UAV Networks

Alireza Shamsoshoara (Northern Arizona University, USA); Mehrdad Khaledi (Suffolk University, USA); Fatemeh Afghah and Abolfazl Razi (Northern Arizona University, USA); Jonathan Ashdown (United States Air Force, USA); Kurt Turck (United States Air Force Research Labs, USA)

In this paper, we study the problem of spectrum scarcity in a network of unmanned aerial vehicles (UAVs) during mission-critical applications such as disaster monitoring and public safety missions, where the pre-allocated spectrum is not sufficient to offer a high data transmission rate for real-time video-streaming. In such scenarios, the UAV network can lease part of the spectrum of a terrestrial licensed network in exchange for providing relaying service. In order to optimize the performance of the UAV network and prolong its lifetime, some of the UAVs will function as a relay for the primary network while the rest of the UAVs carry out their sensing tasks. Here, we propose a team reinforcement learning algorithm performed by the UAV's controller unit to determine the optimum allocation of sensing and relaying tasks among the UAVs as well as their relocation strategy at each time. We analyze the convergence of our algorithm and present simulation results to evaluate the system throughput in different scenarios.

pp. 53-58

Millimeter Wave Remote UAV Control and Communications for Public Safety Scenarios

Wiliam Xia (NYU, USA); Michele Polese (University of Padova, Italy); Marco Mezzavilla (NYU Tandon School of Engineering, USA); Giuseppe Loianno (NYU, USA); Sundeep Rangan (New York University, USA); Michele Zorzi (University of Padova, Italy)

Communication and video capture from unmanned aerial vehicles (UAVs) offer significant potential for assisting first responders in remote public safety settings. In such uses, millimeter wave (mmWave) wireless links can provide high throughput and low latency connectivity between the UAV and remote command center. However, maintaining reliable aerial communication in the mmWave bands is challenging due to the need to support high speed beam tracking and overcome blockage. This paper provides a simulation study aimed at assessing the feasibility of public safety UAV connectivity through a 5G link at 28 GHz. Real flight motion traces are captured during maneuvers similar to those expected in public safety settings. The motions traces are then

incorporated into a detailed mmWave network simulator that models the channel, blockage, beamforming and full 3GPP protocol stack. We show that 5G mmWave communications can deliver throughput up to 1 Gbps with consistent sub ms latency when the base station is located near the mission area.
pp. 59-65

HiPER-V: A High Precision Radio Frequency Vehicle for Aerial Measurements

Maqsood Abdul Careem (University at Albany, SUNY, USA); Jorge A Gomez (University at Albany SUNY, USA); Dola Saha and Aveek Dutta (University at Albany, SUNY, USA)

There is a growing interest towards enabling practical, dynamic and agile wireless applications by systems of independent or cooperative mobile agents such as Unmanned Aerial Vehicles (UAVs). Such mobile UAVs are often constrained on resources like storage, power and radio capabilities and require accurate position information to facilitate many of these wireless applications. In this paper, we introduce HiPER-V, which is a generalized UAV prototype platform to enable a broad range of applications in wireless communications using a single UAV or can be extended to a swarm of UAVs. We implement HiPER-V by using a UAV, equipped with resource constrained radio devices, and high precision position information available via RTK-GPS modules. The details of implementation of HiPER-V and its applicability to a wide variety of applications in wireless communications are presented in this paper. With minimal payload and simple software modification, our solution can be ported to any UAV platform and extended to multiple UAV testbeds that enable an array of research in wireless applications using UAVs.
pp. 66-71

Monday, June 10 14:00 - 17:30

W3: MLCN-IoT workshop

Real Time Attack Detection with Deep Learning

Christian Callegari (RaSS National Laboratory - CNIT & University of Pisa, Italy); Elena Bucchianeri, Stefano Giordano and Michele Pagano (University of Pisa, Italy)

The Internet of Things (IoT) significantly extends the attack surface of the Internet, making the use of an Anomaly-based Intrusion Detection System of paramount importance. Despite in the last years big research efforts have focused on the application of Deep Learning techniques to attack detection, an ultimate real-time solution, able to provide a high detection rate with an acceptable false alarm rate while processing raw network traffic in real time, has still to be identified. For this reason, in this paper we propose an Intrusion Detection System that, leveraging on probabilistic data structures and Deep Learning, is able to process in real time the traffic collected in a backbone network, offering almost optimal detection performance and low false alarm rate. Indeed, the extensive experimental tests, run to validate and evaluate our system, confirm that, with a proper parameter setting, we can achieve about 90% of detection rate, with an accuracy of 0.871.
pp. 72-76

IoT Network Security from the Perspective of Adversarial Deep Learning

Yalin E Sagduyu (Intelligent Automation, Inc., USA); Yi Shi and Tugba Erpek (Virginia Tech, USA)

Machine learning finds rich applications in Internet of Things (IoT) networks such as information retrieval, traffic management, spectrum sensing, and classification. While there is a surge of interest

to understand the security issues of machine learning, their implications have not been understood yet for wireless applications in IoT systems that are susceptible to various attacks due the open and broadcast nature of wireless communications. To support IoT systems with heterogeneous devices of different priorities, we present new techniques built upon adversarial machine learning and apply them to three types of wireless attacks, namely denial of service (DoS) (in terms of jamming), spectrum poisoning, and priority violation attacks. By observing the spectrum, the adversary starts with an exploratory attack to infer the channel access algorithm of an IoT transmitter by building a deep neural network classifier that predicts the transmission outcomes. Based on these prediction results, the wireless attack continues to either jam data transmissions or manipulate sensing results over the air (by transmitting during sensing period) to fool the transmitter into making wrong transmit decisions in test phase (corresponding to an evasion attack). When the IoT transmitter collects sensing results as training data to retrain its channel access algorithm, the adversary launches a causative attack to manipulate the input data to the transmitter over the air. We show that these attacks with different levels of energy consumption lead to significant loss in throughput and success ratio in wireless communications for IoT systems. Then we introduce a defense mechanism that systematically increases the uncertainty of the adversary at the inference stage and improves the performance. Results provide new insights on how to attack and defend IoT networks using deep learning.
pp. 77-85

A Convolutional Neural Network Approach for Classification of LPWAN Technologies: Sigfox, LoRA and IEEE 802.15.4g

Adnan Shahid (Gent University - imec, Belgium); Jaron Fontaine (Ghent University - imec, Belgium); Miguel Camelo (University of Antwerp, Belgium); Jetmir Haxhibeqiri (IDLab, Ghent University - imec, Belgium); Martijn Saelens (Ghent University, Belgium); Zaheer Khan (University of Oulu, Finland); Ingrid Moerman (Ghent University - imec, Belgium); Eli De Poorter (Ghent University & Imec, Belgium)

This paper presents a Convolutional Neural Network (CNN) approach for classification of low power wide area network (LPWAN) technologies such as Sigfox, LoRA and IEEE 802.15.4g. Since the technologies operate in unlicensed sub-GHz bands, their transmissions can interfere with each other and significantly degrade their performance. This situation further intensifies when the network density increases which will be the case of future LPWANs. In this regard, it becomes essential to classify coexisting technologies so that the impact of interference can be minimized by making optimal spectrum decisions. State-of-the-art technology classification approaches use signal processing approaches for solving the task. However, such techniques are not scalable and require domain-expertise knowledge for developing new rules for each new technology. On the contrary, we present a CNN approach for classification which requires limited domain-expertise knowledge, and it can be scalable to any number of wireless technologies. We present and compare two CNN-based classifiers named CNN-based on in-phase and quadrature (IQ) and CNN-based on Fast Fourier Transform (FFT). The results illustrate that CNN-based on IQ achieves classification accuracy close to 97% similar to CNN based on FFT and thus, avoiding the need for performing FFT.
pp. 86-93

A Machine Learning Approach Using Classifier Cascades for Optimal Routing in Opportunistic Internet of Things Networks

Vidushi Vashishth (Netaji Subhas Institute of Technology, India); Anshuman Chhabra (University

of California, Davis, USA); Deepak Kumar Sharma (Netaji Subhas Institute of Technology, University of Delhi, India)
Routing in Opportunistic Internet of Things Networks (OppIoT) is an involved problem, because the network is intermittently connected and source to destination end-to-end paths are non-existent. Moreover, Machine Learning (ML) has recently achieved great success in multiple domains and is now being applied to automate routing in Opportunistic Networks (OppNets) which are similar in characteristics to OppIoT, through protocols such as MLProph and KNNR. In this paper, we utilize cascade learning, a form of ensemble based ML, for improved routing in OppIoT. Through simulations we show that our proposed protocol, CAML, outperforms ML based protocols (MLProph and KNNR), and also traditional well-performing protocols (HBPR and PRoPHET), on a wide range of performance metrics.
pp. 94-102

A Stackelberg Game based River Water Pollution Monitoring System using LoRa Technology

Preti Kumari (IIT(BHU), India); Hari Prabhat Gupta (Indian Institute of Technology (BHU) Varanasi, INDIA, India); Tanima Dutta (IIT (BHU) Varanasi, India)
Water is one of the necessary things required for living. Sensor networks play a major role in detecting the pollution level of the river water. Detection of the sudden changes in the pollution level of the river water is a challenging problem because it requires continuous monitoring of the river water. In this paper, we propose a Stackelberg Game based system to detect the sudden changes of the pollution level of the river water. We use Long Range (LoRa) technology for transferring the sensory data to the server. The LoRa uses different Spreading Factors which helps to reduce the communication energy and enhances the lifetime of the system. We demonstrate the utility of the system and study the impact of the sudden changes of the pollution level of the water on the energy consumption of the system.
pp. 103-107

W4: CyberEdge workshop

Adaptive Resource Management for a Virtualized Computing Platform within Edge Computing

Thembelihle Dlamini and Angel Fernandez Gambin (University of Padova, Italy)
In virtualized computing platforms, energy consumption is related to the computing-plus-communication processes. However, most of the proposed energy consumption models and energy saving solutions found in literature consider only the active Virtual Machines (VMs), thus the overall operational energy expenditure is usually related to solely the computation process. To address this shortcoming, in this paper we consider a computing-plus-communication energy model, within the Multi-access Edge Computing (MEC) paradigm, and then put forward a combination of a traffic engineering- and MEC Location Service-based online server management algorithm with Energy Harvesting (EH) capabilities, called Automated Resource Controller for Energy-aware Server (ARCES), for autoscaling and reconfiguring the computing-plus-communication resources. The main goal is to minimize the overall energy consumption, under hard per-task delay constraints (i.e., Quality of Service (QoS)). ARCES jointly performs (i) a short-term server demand and harvested solar energy forecasting, (ii) VM soft-scaling, workload and processing rate allocation and lastly, (iii) switching on/off of transmission drivers (i.e., fast tunable lasers) coupled with the location-aware traffic scheduling. Our numerical results reveal that ARCES achieves on average energy savings of 69%, and an energy consumption ranging from 31%-45%and from 21%-25% at different values of per-VM reconfiguration cost, with respect to the case where

no energy management is applied.
pp. 108-116

Compress or Interfere?

Alaa Awad Abdellatif (Politecnico di Torino, Italy); Lutfi Samara, Amr Mohamed, Abdulla K Al-Ali and Aiman Erbad (Qatar University, Qatar); Mohsen Guizani (University of Idaho, USA)

Rapid evolution of wireless medical devices and network technologies has fostered the growth of remote monitoring systems. Such new technologies enable monitoring patients' medical records anytime and anywhere without limiting patients' activities. However, critical challenges have emerged with remote monitoring systems due to the enormous amount of generated data that need to be efficiently processed and wirelessly transmitted to the service providers in time. Thus, in this paper, we leverage full-duplex capabilities for fast transmission, while tackling the trade-off between Quality of Service (QoS) requirements and consequent self-interference (SI) for efficient remote monitoring healthcare systems. The proposed framework jointly considers the residual SI resulting from simultaneous transmission and reception along with the compressibility feature of medical data in order to optimize the data transmission over wireless channels, while maintaining the application's QoS constraint. Our simulation results demonstrate the efficiency of the proposed solution in terms of minimizing the transmission power, residual self-interference, and encoding distortion.
pp. 117-122

Algorithms for Provisioning Edge Computing Resources to Minimize Data Transport Costs

Nima M Seyedtalebi (University of Kentucky, USA)

Edge computing is a type of distributed computing in which computation might be performed at or near the edges of the network. This trend is driven by the disparity in growth between computational capacity and network performance. By locating computation at or near places where data is generated (e.g. end-user devices), one can minimize the total cost of computation by minimizing unnecessary data movement and thus circumvent the bottleneck. In this paper, we propose a simple model and several approximation algorithms for deciding where computation should take place to minimize the cost of data movement in a dynamic edge computing environment.
pp. 123-131

Urban Anomaly Detection by Processing Mobile Traffic Traces with LSTM Neural Networks

Hoang Duy Trinh (Centre Tecnològic de Telecomunicacions de Catalunya, Spain); Lorenza Giupponi and Paolo Dini (Centre Tecnològic de Telecomunicacions de Catalunya (CTTC), Spain)

Detecting urban anomalies is of upmost importance for public order management, since they can pose serious risks to public safety if not timely handled. However, monitoring large urbanities requires complex systems that can potentially lead to elevated costs. In this paper, we discuss the opportunity of exploiting the mobile network as a supplementary sensing platform for detecting urban anomalies. To favour the reliable and low latency anomaly recognition, we rely on a Multi-access Edge Computing (MEC) architecture, which enables a deep and detailed mobile traffic characterization almost in real-time and allows for a performance-responsive service, that is crucial in our problem. We focus on urban anomaly detection, by monitoring known events that gather a high concentration of people. The mobile network information are collected from LTE Physical Downlink Control Channel (PDCCH), which contains the radio scheduling information and has the benefit of being unencrypted and fine-grained, since the messages are exchanged every LTE subframe of 1 ms. Detecting specific anomaly situations, in which the radio resources become

scarce, is fundamental to avoid congested traffic issues and to keep the user QoS at adequate levels. To this purpose, we design an anomaly detection system based on Long Short-Term Memory (LSTM) Neural Networks, which are advanced machine learning algorithms, to deal with sequential and recurrent inputs. We demonstrate that a stacked LSTM architecture is able to learn to identify traffic anomalies provoked by a rapid growth of the users, when a crowded event takes place nearby the monitored area. The numerical results show that the proposed algorithm can reach an F-score of 1 and it is unbeaten by state-of-the-art unsupervised algorithms.
pp. 132-139

Source Localization and Tracking for Dynamic Radio Cartography using Directional Antennas
Mohsen Joneidi, Hassan Yazdani, Azadeh Vosoughi and Nazanin Rahnavard (University of Central Florida, USA)
Utilization of directional antennas is a promising solution for spectrum sensing and source localization. Sensors equipped with directional antennas should constantly scan the space in order to track sources and discover new activities in the area of interest. In this paper, first we propose anew formulation that unifies received-signal-strength (RSS) and direction of arrival (DoA) in a compressive sensing approach.The measurement matrix is a function of beamforming vector of sensors. Then, we propose to optimize beams in order to sense the spectrum more efficiently, track active PUs and cover spectrum activities of the area of interest. In many practical scenarios there is no fusion center to integrate received data. The distributed version of our algorithm is also presented. Experimental results shows a significant gain in source localization comparison to omni-directional antennas. Moreover, the estimated power map of PUs over time using the proposed method for directional antennas is plotted which shows the accuracy of estimation and signal recovery.
pp. 140-148

Tuesday, June 11

Tuesday, June 11 11:00 - 12:30

C1: Best Paper Award Session

In Memoriam: Mario Gerla
Chair: Ngwe Thawdar (Air Force Research Laboratory, USA)

PEC: Synthetic Aperture RFID Localization with Aperture Position Error Compensation
Run Zhao, Dong Wang, Qian Zhang, Haonan Chen and Huatao Xu (Shanghai Jiao Tong University, P.R. China)
In recent years, location-based services have been widely applied not only in daily life but also in automation industries. As one of main location sensing technologies, RFID based localization has attracted increasing attention. Existing synthetic aperture RFID localization systems use the inverse correlation filter to reconstruct holograms and achieve satisfactory accuracy. However, these methods require accurate aperture positions for theoretical signal construction, while the ubiquitous aperture uncertainty in practice causes non-negligible performance degradation. In this paper, we present PEC, an accurate synthetic aperture RFID localization system with aperture position error compensation, which has a major advantage over the classic systems for no need to know the exact trajectory of the synthetic aperture. We first build a mathematical model for localization and merge all coherent received signals to estimate the tag position. Then we treat the aperture position error as

a part of the localization model and propose an iterative algorithm which can alternately estimate both the tag position and the aperture position error. We have implemented and evaluated PEC using commercial-off-the-shelf (COTS) RFID devices. Extensive experimental results show that it achieves the cm-level accuracy with aperture position error in noisy environments, which proves its effectiveness and robustness.
pp. 149-157

Learning-based Blockage Prediction for Robust Links in Dynamic Millimeter Wave Networks

Masoud Zarifneshat, Li Xiao and Jiliang Tang (Michigan State University, USA)

To employ millimeter wave technology in the 5G standard, two inherent challenges need to be addressed in dynamic outdoor environments. Firstly, different types of obstacles can easily block the links. Secondly, the link quality can drop significantly in a mobile environment. It is critical to discriminate between the two different situations to take appropriate actions. The existing work to make the distinction is based on RSSI variation measured in a time window, which is very time-consuming leading to large volume of data loss in order to achieve high accuracy. In this paper, we propose a learning-based prediction framework to classify link blockage and link movement efficiently and quickly. A classifier is trained with data blockage instances using different learning methods and is used to make a prediction based on diffraction values on different multipath components formed around a receiver. The simulations show that the prediction framework can predict blockage with close to 90\% accuracy. The prediction framework will eliminate the need for having time-consuming methods to discriminate between link movement and link blockage. Experiments show that our framework does not need large amount of training data to get to the desired prediction accuracy.
pp. 158-166

Grid Software Defined Radio Network Testbed for Hybrid Measurement and Emulation

Kapil Dandekar, Simon Begashaw, Marko Jacovic, Alex Lackpour, Ilhaan Rasheed, Xaime Rivas Rey and Cem Sahin (Drexel University, USA); Sharif Shaher (Echo Ridge, USA); Geoffrey Mainland (Drexel University, USA)

Traditional approaches to experimental characterization of wireless communication systems typically involves highly specialized and small-scale experiments to examine narrow aspects of each of these applications. We present the Grid SDR testbed, a unified experimental framework to rapidly prototype and evaluate these diverse systems using: (i) field measurements to evaluate real time transceiver and channel-specific effects and (ii) network emulation to evaluate systems at a large scale with controllable and repeatable channels. We present the hardware and software architecture for our testbed, and describe how it being used for research and education. Specifically, we show experimental network layer metrics in different application domains, and discuss future opportunities using this unique experimental capability.
pp. 167-175

X-Burst: Enabling Multi-Platform Cross-Technology Communication between Constrained IoT Devices

Rainer Hofmann, Carlo Alberto Boano and Kay Römer (Graz University of Technology, Austria)

Cross-technology communication (CTC) allows devices employing incompatible wireless technologies to directly exchange information without the need of expensive gateways. Existing work on CTC has showcased the ability of exchanging data between diverse wireless standards, but has not analysed the challenges nor tackled the problem of enabling CTC between multiple constrained IoT platforms with different characteristics. Indeed, CTC schemes are often hacked on

very specific hardware platforms, which results in a lack of a general, portable solution. Furthermore, CTC has always been tested as a standalone piece of functionality, and its seamless integration with the classical operations of a constrained IoT device remains an open challenge. In this paper, we present X-Burst, a portable framework that allows multiple constrained IoT platforms with diverse characteristics to seamlessly interact using CTC. X-Burst allows to customize the CTC working principle (e.g., how information is encoded, or the alphabet used to encode a symbol) and enables the combination of different encoding and decoding strategies independently of the employed hardware platform. Thanks to its high modularity, X-Burst also simplifies the development of alternative CTC implementations and makes it easy to compare different approaches. We integrate X-Burst into the Contiki operating system without changing Contiki's core functions and allow an IoT device to seamlessly support CTC in parallel to its normal operations. We then showcase the functionality of X-Burst by enabling a bidirectional CTC between off-the-shelf heterogeneous IoT platforms based on IEEE 802.15.4 and Bluetooth Low Energy (BLE). An experimental evaluation further shows X-Burst's small memory footprint and analyses the robustness and throughput of different encoding schemes.
pp. 176-184

Tuesday, June 11 13:40 - 15:40

A1: Activity Recognition

Chair: Adnan Shahid (Gent University - imec, Belgium)

Commercial Wi-Fi Based Fall Detection with Environment Influence Mitigation

Lei Zhang, Zhirui Wang and Liu Yang (Tianjin University, P.R. China)

Motivated by the urgent demands of indoor fall detection, significant progress has been made to explore Wi- Fi based fall detection techniques that utilize the information collected by commercial Wi-Fi signals to infer falling without carrying a dedicated device. Existing commercial Wi-Fi based fall detection systems, though yielding reasonably good performance in certain cases, are faced with a major challenge. The Wi-Fi signals arriving at the receiving devices usually carry substantial information specific to the environment where falling happens. Due to this reason, a fall detection model trained in one specific environment does not work well in the other. Furthermore, it is labor-intensive and time-consuming to acquire sufficient data and rebuild fall detection model in each new environment. To address this challenge, we propose TL-Fall, a transfer-learning based device free fall detection system. Specifically, the fall detection model is trained with labeled data to derive knowledge in the old environment. With the derived knowledge, the fall detection model working in the new environment can be trained with only a few labeled data. The effective across environment knowledge reuse mitigates the environmental influence and maintains the satisfied fall detection accuracy as well. The extensive experiments are conducted on TL-Fall in typical indoor environment. The experimental results demonstrate the superior effectiveness of TL-Fall, with 86.83% fall detection sensitivity and 84.71% fall detection specificity on average.
pp. 185-193

Pushing the Limit of CSI-based Activity Recognition: An Enhanced Approach via Packet Reconstruction

Youjing Lu and Fan Wu (Shanghai Jiao Tong University, P.R. China); Shaojie Tang (University of Texas at Dallas, USA); Linghe Kong and Guihai Chen (Shanghai Jiao Tong University, P.R. China)

Fine-grained and complete Channel State Information (CSI) is essential for emerging CSI-based

activity recognition applications. However, many probe packets collected for CSI measurements may be lost due to co-channel interferences and other malfunctions in practice, such as link interruptions, and thus limit the further applications of these CSI-based activity recognitions. To overcome this limitation, we propose an IMproved cOmpressive Sensing bAsed mIssing packet reCovery method, named IMOSAIC, to locate the lost probe packets and to reconstruct the missing CSIs, and thus improve the accuracy and the robustness of CSI-based activity recognitions. The key idea is to trace the probe packet flow to locate the positions of lost packets, derive the CSI Matrix from CSI measurements, and use improved compressive sensing technique to reconstruct the missing CSIs. We mainly address challenges in locating the lost packets, transforming CSI measurements into CSI Matrix, and digging up CSI measurement correlations and inherent low-rank properties to reconstruct the lost packets. Furthermore, experiment results show that IMOSAIC outperforms existing interpolation methods on reconstructing the lost packets, and can achieve an average recovery accuracy of 80.21%, when 90% of packets are lost, and the reconstructed CSI datasets can improve the activity recognition accuracy obviously.
pp. 194-202

G-Fall: Device-free and Training-free Fall Detection with Geophones

Yandao Huang, Wenqiang Chen, Hongjie Chen, Lu Wang and Kaishun Wu (Shenzhen University, P.R. China)

The inevitable aging trend of the world's population brings a lot of challenges to the health care for the elderly. For example, it is difficult to guarantee timely rescue for a single-resided elder who falls at home. Under this circumstance, a reliable automatic fall detection machine is in great need for emergent rescue. However, the state-of-the-art fall detection systems are suffering from serious privacy concerns, having a high false alarm or being cumbersome for users. In this paper, we propose a device-free fall detection system, namely G-Fall, based on geophones. We first decompose the falling mode and characterize it with time-dependent floor vibration features. By leveraging Hidden Markov Model (HMM), our system is able to recognize the fall event precisely and achieve training-free recognition. It requires no training from the elderly but only an HMM template learned in advance through a small number of training samples. To reduce the false alarm rate, we propose a novel reconfirmation mechanism, namely Energy-of-Arrival (EoA) positioning to assist in recognizing a human's fall. Extensive experiments have been conducted on 12 human subjects. The results demonstrate that G-Fall achieves a 95.74% recognition precision with a false alarm rate of 5.30\% on average. Furthermore, with the assistance of EoA, the false alarm rate is reduced to nearly 0%.
pp. 203-211

ReActor: Real-time and Accurate Contactless Gesture Recognition with RFID

Shigeng Zhang, Chengwei Yang, Xiaoyan Kui and Jianxin Wang (Central South University, P.R. China); Xuan Liu (Hunan University, P.R. China); Song Guo (The Hong Kong Polytechnic University, Hong Kong)

Contactless gesture recognition has emerged as a promising technique to enable diverse smart applications, e.g., novel human-machine interaction. Among others, gesture recognition based on radio frequency identification (RFID) is preferred due to its prevalent availability, low cost, and ease in deployment. However, current RFID-based gesture recognition approaches usually use profile template matching to distinguish different gestures, making them suffer from large recognition latency and fail to support real-time applications. In this paper, we propose a real-time and accurate contactless RFID-based gesture recognition approach called \emph{ReActor}.

ReActor uses machine learning rather than time-consuming profile template matching to distinguish different gestures, and thus achieves both very low recognition latency and high recognition accuracy. The major challenge of our approach is to determine a set of suitable attributes that can preserve the profile features of the signals related to different gestures. We combine two types of attributes in ReActor: the statistics of the signal profile that characterize coarse-grained features and the wavelet (transformation) coefficients of the signal profile that characterize fine-grained local features, both of which can be calculated fast. Experimental results demonstrate that ReActor can recognize a gesture with average latency less than 51ms, two orders of magnitude faster than state-of-the-art approaches based on profile template matching. Furthermore, ReActor also achieves higher recognition accuracy than previous works due to its optimized attribute set.
pp. 212-220

Occupancy Analytics in Retail Stores Using Wireless Signals

Saandeep Depatla (UCSB, USA); Yasamin Mostofi (University of California, Santa Barbara, USA)
In this paper, we propose a new framework to estimate the occupancy dynamics of the shoppers over a whole retail store, based on the received power measurements of wireless links that are installed in only a small number of aisles, and without relying on people to carry any device. More specifically, we utilize the received power measurements collected by a small number of wireless links installed in only a few aisles of a retail store and show that we can estimate the rate of arrival of people in all the aisles of the retail store. We first show how a pair of wireless links in an aisle can estimate the rate of arrival of people into that aisle for the general case where people can have a bi-directional flow. We then propose a new framework to estimate the rate of arrival of people into all the aisles of the retail store, using the received power measurements of a number of wireless links that are installed in only a few aisles. Our proposed approach utilizes the sparsity in the spatial and temporal gradient of the occupancy dynamics and poses an optimization problem to estimate the arrival rates over the whole store based only on a very small number of wireless measurements. We thoroughly validate our framework with several experiments in three different retail stores - Kmart and two anonymous retail stores (Store-2 and Store-3), using the RSSI measurements of Bluetooth Low Energy (BLE) Chips. Our results confirm that our framework can accurately estimate the rate of arrival of people into different aisles of a retail store with minimal wireless sensing. More specifically, we show that our approach can estimate the rate of arrival of people in different aisles of a store, with an average root mean square of 0.03 people/minute, when averaged over all the aisles and all the time, and while reducing the number of required wireless links by 57%.
pp. 221-229

B1: Concurrent and Cooperative Communication

Chair: Sabit Ekin (Oklahoma State University, USA)

AdaComm: Tracing Channel Dynamics for Reliable Cross-Technology Communication

Weiguo Wang (Tsinghua University, P.R. China); Xiaolong Zheng (Beijing University of Posts and Telecommunications, P.R. China); Yuan He and Xiuzhen Guo (Tsinghua University, P.R. China)
Cross-Technology Communication (CTC) is an emerging technology to enable direct communication between devices that follow different standards. The performance of the existing CTC approaches is easily affected by the channel dynamics, due to 1) lack of appropriate indicators of the channel condition and 2) inability to be adaptive in face of channel dynamics. Most of the existing CTC approaches adopt indirect indicators (e.g. packet error rate) to trace the channel

dynamics. A significant variation in the indicator's value may trigger the adjustment of communication, which enlarges the distinctiveness of signal features, so as to fit them for the predetermined decoding model. Such reactive methods cannot capture the short-term channel dynamics and thus fail to maintain reliable performance in fast-changing channels. In this paper, we propose AdaComm, a general online adaptive CTC framework that maintains reliable communication performance in dynamic channels. Instead of adjusting the CTC sender, AdaComm leverages the correctly decoded data at the CTC receiver. It contains a decoding model that automatically learns the effective features in current channel state. By directly using the raw received signals, AdaComm comprehensively captures the channel state in the decoding model and avoids information loss caused by manual feature extraction. We implement AdaComm and evaluate its performance in different scenarios. The results demonstrate that AdaComm effectively can reduce the SER by 72.9% and 49.2% for the CSI-based and the RSSI-based CTC respectively, compared with the existing approach.
pp. 230-238

Playing with Fire: Exploring Concurrent Transmissions in Ultra-wideband Radios

Davide Vecchia, Pablo Corbalan, Timofei Istomin and Gian Pietro Picco (University of Trento, Italy)

Concurrent transmissions can be used to enhance network reliability and scalability and to reduce energy consumption and latency. This paper studies their applicability for communication and ranging in UWB networks, where they are hitherto largely unexplored. To this end, we follow an experiment-driven approach and show that i) different pulse repetition frequencies virtually double the number of non-interfering channels, ii) concurrent transmissions with different preamble codes are unreliable, unless transmitters are tightly synchronized, and iii) under the same RF configuration, UWB radios are very likely to receive one of the packets transmitted concurrently by multiple senders, unlocking opportunities similar to those exploited in low-power narrowband radios. We argue that our findings can inform the design of novel communication and ranging protocols exploiting the unique advantages of concurrent transmissions, potentially inspiring a new wave of research on UWB radios.
pp. 239-247

Machine Learning based Dynamic Cooperative Transmission Framework for IoUT Networks

Ahmad El-Banna (Benha University, Faculty of Engineering at Shoubra, Egypt & Shenzhen University, P.R. China); Ahmed Zaky (Benha University, Egypt); Basem M. ElHalawany (Benha University & Shoubra Faculty of Engineering, Egypt); Joshua Huang and Kaishun Wu (Shenzhen University, P.R. China)

Underwater channels are considered challenging media in communication due to the harsh nature of such environments. However, dynamic transmission can assist in finding sub-optimal solutions by adaptively changing the employed techniques, e.g. forwarding scheme between nodes and the transmitted signal intensity control, to compromise for the instantaneous fluctuations in various underwater environments. Additionally, Machine Learning (ML) techniques can provide appropriate solutions for various problems e.g. routing, resource allocation, and energy-efficiency to further enhance the quality of the communication systems. In this paper, we propose a novel dynamical transmission framework for multi-hop Internet of Underwater Things (IoUT) and underwater networks to fit for various conditions. The proposed framework employs a heuristic forwarding scheme selection approach beside an adaptive transmission signal intensity method. We also propose a decision-tree based ML-model that adaptively learns the proper forwarding method

beside the appropriate amount of the transmitted signal intensity for each relay node to minimize the transmission error rate and the power consumption depending on numerous parameters e.g. node location, link reliability and certain water quality metrics such as water temperature, depth, and pH measurements. The model achieves remarkable accuracy for training and testing patterns beyond the 99%.
pp. 248-256

MatchMaker: An Inter-operator Network Sharing Framework in Unlicensed Bands

Mohammed Hirzallah (University of Arizona, USA); Yong Xiao (Huazhong University of Science and Technology, P.R. China); Marwan Krunz (University of Arizona, USA)

In this paper, we consider the scenario wherein mobile network operators (MNOs) share network infrastructure for operating 5G new radio (NR) services in unlicensed bands, whereby they reduce their deployment cost and extend their service coverage. Conserving privacy of MNOs' users, maintaining fairness with coexisting technologies such as Wi-Fi, and reducing communication overhead between MNOs are among top challenges limiting the feasibility and success of this sharing paradigm. To resolve above issues, we present MatchMaker, a novel framework for joint network infrastructure and unlicensed spectrum sharing among MNOs. MatchMaker extends the 3GPP's infrastructure sharing architecture, originally introduced for licensed bands, to have privacy-conserving protocols for managing the shared infrastructure. We also propose a novel privacy-conserving algorithm for channel assignment among MNOs. Although achieving an optimal channel assignment for MNOs over unlicensed bands dictates having global knowledge about MNOs' network conditions and their interference zones, our channel assignment algorithm does not require such global knowledge and maximizes the cross-technology fairness for the coexisting systems. We let controllers, managing the shared infrastructure, learn potential interference among MNOs and Wi-Fi systems by asking MNOs to propose their preferred channel assignment and monitor their average contention delay overtime. Controllers only accept/reject MNOs' proposals and build contention graph between all coexisting systems. Our results show that MatchMaker improves the overall fairness and achieves up to 94% of the optimal alpha-fairness-based channel assignment while still preserving MNOs' privacy.
pp. 257-265

DuoRelay: Parallel Interference Nulling using Full-duplex Relaying

Ananya Mahanti and Wei-Han Chen (The Ohio State University, USA); Prasun Sinha (Ohio State University, USA)

In recent years, the volume of uplink traffic in our networks has grown and become increasingly diverse. Typically, concurrent uplink transmissions can be made possible by allowing the APs to collaborate over the wired backbone for control signalling as well as data decoding. In our paper, we remove the dependency over the wired backbone for data decoding without requiring any pre-coding constraints at the clients' end. Our paper contrasts with other existing works which can decode concurrent uplink data-streams without the backbone as they either need multiple antennas at the transmitters/receivers, pre-coding at the transmitters or antennas to be physically moved at the receivers. In our paper, we address the problem space of single antenna transmitters and receivers and enable concurrent uplink transmissions by leveraging the recent developments in full-duplex wireless communication. We make each of our APs act as full-duplex relay nodes. Each AP cancels its own client's signal at the other AP, thus enabling themselves to clearly hear their own clients without requiring any pre-coding at the clients' end. We implemented and evaluated our scheme using USRP N210 software defined radios and achieved upto 1.48x throughput gains over

TDMA. The throughput improvement over TDMA is upto 1.7x in our system level simulations with our greedy node selection algorithm.
pp. 266-274

Tuesday, June 11 16:00 - 18:00

A2: Localization and Tracking

Chair: Ravishankar Chamarajnagar (VMWare, USA)

SparseTag: High-Precision Backscatter Indoor Localization with Sparse RFID Tag Arrays
Chao Yang (Auburn University, USA); Xuyu Wang (California State University, Sacramento, USA); Shiwen Mao (Auburn University, USA)
In this paper, we study the problem of utilizing a sparse RFID tag array for backscatter indoor localization. We first theoretically and experimentally validate the feasibility of using RFID tag array for direction of arrival (DOA) estimation. We then present the SparseTag system, which leverages a novel sparse RFID tag array for high-precision backscatter indoor localization. The SparseTag system includes sparse array processing, difference co-array design, DOA estimation using a spatial smoothing based method, and a localization method, where a robust channel selection method based on the RFID tag array is proposed for mitigating the indoor multipath effect. The SparseTag system is implemented with commodity RFID devices. Its superior performance is validated in two different environments with extensive experiments.
pp. 275-283

Triangular Antenna Layout Facilitates Deployability of CSI Indoor Localization Systems
Xinyu Tong (Shanghai Jiao Tong University, P.R. China); Hao Li (Shanghai Jiao Tong Unversity, P.R. China); Xiaohua Tian (Shanghai Jiao Tong University, P.R. China); Xinbing Wang (Shanghai Jiaotong University, P.R. China)
Channel state information (CSI) based Wi-Fi localization can achieve admirable decimeter-level accuracy; however, such systems require labor-intensive site survey to calibrate the AP position and the antenna array orientation, which hinders practical large-scale deployment. In this paper, we reveal an interesting finding that the calibration efforts for deploying the CSI localization system can be significantly reduced by simply replacing the ordinary linear antenna layout of the AP with the triangular layout. In particular, we first propose a systematical evaluation mechanism to show the fundamental reason why linear antenna layout usually leads to serious errors and why triangular antenna layout is better off. Then we present an autonomous self-calibrating method to significantly facilitate site survey for deploying CSI localization systems. Moreover, we redesign the classic MUltiple SIgnal Classification (MUSIC) algorithms to accommodate the triangular antenna layout. We build a testbed with COTS devices and conduct comprehensive experiments. Results show that triangular antenna layout can achieve 80% angle of arrival (AoA) measurement error within 9◦ for any direction in contrast to 16◦ based on linear antenna layout. Moreover, we can realize promising localization accuracy as previous works even without labor-intensive site survey, where 80% localization error is within 0:60m.
pp. 284-292

iTracker: Towards Sustained Self-Tracking in Dynamic Feature Environment with Smartphones
Boyuan Sun, Qiang Ma, Zhichao Cao and Yunhao Liu (Tsinghua University, P.R. China)
Self-tracking at 6 degrees of freedom in real-time is essential in lots of emerging applications such

as VR/AR/MR simulation, indoor navigation, and so on. With the development of built-in sensors in smartphones, many self-tracking solutions have appeared. Many researchers try to utilize vision-based approaches combined with an Inertial Measure Unit (IMU) to realize self-tracking with smartphones. After testing these approaches, however, we find that tracking would be lost in four such common scenarios: 1) When the IMU rotates fast or for a long period of time, it will cause serious delays in orientation tracking; 2) The scenes where background features are not distinct enough; 3) When the smartphone moves fast, image features become quite different in successive frames; 4) Unstructured scenes where background features are not static. To address these issues, we propose iTracker, which utilizes Real-time Step-Length Adaption Algorithm to solve the scenario (1) and a Parallel-Multi-State Local Recovery method to deal with scenarios (2)-(4). Extensive experiments show that iTracker realizes robust and accurate self-tracking in these four scenarios with an error of 0.7% throughout the whole trajectory.
pp. 293-301

Trans-Sense: Real Time Transportation Schedule Estimation Using Smart Phones

Ali Abdelaziz (Egypt-Japan University for Science and Technology & Aswan University, Egypt); Amin Shoukry (Egypt-Japan University of Science and Technology, Egypt); Walid Gomaa (Egypt Japan University of Science and Technology, Egypt); Moustafa Youssef (Alexandria University, Egypt)

Developing countries suffer from traffic problems, poorly planned road/rail networks and lack of access to public transportation facilities. On one hand, this context results in an increase in fuel expenditure, pollution level, monetary losses, massive delays and less productivity. On the other hand, it has a negative impact on the commuters feelings and modes. Availability of realtime transit information - by providing public transportation facilities with GPS systems - helps in estimating a passenger waiting time. However, such solution is expensive for developing countries such as Egypt. This paper aims at designing and implementing a user friendly mobile-based solution to estimate the expected waiting time of a passenger in public transit systems. In particular, it is conducted on the light rail transit (LRT) facility of Alexandria city, Egypt. It can help passengers to better manage their time and/ or activities. The basic idea is that the phone speed can be correlated with the GPS data to extract the semantics hidden in the filtered GPS points, further estimate the average waiting time at stations, traffic lights and dynamic speed estimation of the elapsed time between stations that reflects tram's speed. More importantly, we predict also the remaining time to get on/off a vehicle and Correctly estimated and constructed Alexandria's real time tram schedule. Trans-Sense has been evaluated using real data collected for over 800 hours, and on daily basis, by many riders, accompanied by their Android's phones, using different tram lines at different time spans. Trans-Sense achieved an average recall and precision of 95.35% and 90.1%, respectively, in discriminating between stations and traffic lights. Moreover, Trans-Sense is able to calculate the stations' dimensions with an accuracy of 95.714%, can incorporate more stations based only on the information provided from GPS.
pp. 302-309

WiZoom: Accurate Multipath Profiling using Commodity WiFi Devices with Limited Bandwidth

Hua Xue, Jiadi Yu, Yanmin Zhu, Li Lu, Shiyou Qian and Minglu Li (Shanghai Jiao Tong University, P.R. China)

Multipath profiling is to characterize multipath components of wireless channels, which can be done using Channel State Information (CSI) from WiFi devices. To do so with satisfactory accuracy, recent studies rely on either a large number of receiving antennas or large bandwidth.

However, it is difficult for commodity WiFi devices to meet these requirements. In this paper, we propose a scheme, WiZoom, that can perform accurate multipath profiling using single-band CSI from commodity WiFi devices. In order to achieve accurate multipath profiling with limited bandwidth, WiZoom first incorporates the MUltiple SIgnal Classification (MUSIC) algorithm with CSI to estimate ToAs of multipath components, and then combines multiple antennas to improve the resolution of ToA estimation. WiZoom further estimates attenuations and phase shifts for multipath components using the ToAs. So far, multipath components are fully characterized, and all these estimated parameters form the mulitipath profile. We evaluate the performance of WiZoom using commodity WiFi devices in real environment, and results show that WiZoom achieves high accuracy in multipath profiling.
pp. 310-318

B2: Spectrum

Chair: Francesco Restuccia (Northeastern University, USA)

TF2AN: A Temporal-Frequency Fusion Attention Network for Spectrum Energy Level Prediction

Kehan Li, Zebo Liu, Shibo He and Jiming Chen (Zhejiang University, P.R. China)

Modeling and predicting radio spectrum are significant for better understanding the behavior of spectrum, managing their usage as well as optimizing the performance of dynamic spectrum access. Most of the existing works concentrate on predicting the occupation status of the spectrum via threshold-based binary time series, ignoring abundant frequency correlations. In fact, precisely predicting the energy level of the radio spectrum can provide richer information for applications such as characterizing the spectrum trending for earlier anomaly detection and estimating the channel quality for efficient spectrum sharing. However, the precise prediction is challenging due to the interference from both intra-spectrum and external factors. In this paper, we propose a temporal-frequency fusion attention network to model the complex internal and external correlations for precise prediction. More specifically, our framework consists of three major components: 1) an image processing based robust signal detection algorithm to locate the signal as model input. 2) an attention-based Long Short-term Memory network to model the temporal-frequency correlation of the spectrum. 3) a generalized fusion module to take in the external factors from heterogeneous domains. Extensive experiments are conducted on real-world datasets collected by our spectrum monitoring station deployed in the city of Hangzhou, China, which shows that the proposed signal detection algorithm is robust for frequency bands with different signal to noise ratios. Furthermore, experimental results demonstrate that our method outperforms seven baseline methods in terms of prediction accuracy. The sensitivities of hyper-parameters are analyzed and the interpretability is also well discussed to prove the effectiveness of our method.
pp. 319-327

Online Data Quality Learning for Quality-Aware Crowdsensing

Xiangyu Zhang and Xiaowen Gong (Auburn University, USA)

Crowdsensing has found a variety of applications (e.g., spectrum sensing, environmental monitoring) by leveraging the "wisdom" of a potentially large crowd of mobile users as "workers". The value of data collected in crowdsensing heavily depends on the quality of data provided by the workers participating in a crowdsensing task. In general, the quality of data varies for different workers. To fully exploit the potential of crowdsensing, it is important for the crowdsensing requester to know workers' data quality, based on which the requester allocates tasks to workers and aggregates data from workers. Such quality-aware crowdsensing can greatly improve the value and

usefulness of data in crowdsensing. However, the quality of workers' data is often unknown to the requester (due to, e.g., workers' characteristics are unknown). In this paper, under a dynamic multi-task crowdsensing framework, we devise an online data quality learning algorithm that learns the data quality of workers from their data on the fly, while making use of the learned quality information to perform task allocation and data aggregation. Compared to prior online learning algorithms (such as those for the multi-armed bandit problems), our algorithm needs to overcome the challenge that the ground truth of the interested variable is unknown. We show that under some mild conditions, our algorithm converges to the offline optimal strategy over time, and have a regret in the order of O(logt) compared to the offline optimal strategy. We also extend the analytical results for the simple average rule to the weighted average rule. We demonstrate the efficiency of the algorithm using simulation results.
pp. 328-336

Nearly-Optimal Resource Allocation for Coexisting Industrial Wireless Networks with Line Topologies

Jialin Zhang (ShenYang Institute of Automation Chinese Academy of Sciences, P.R. China); Wei Liang (Shenyang Institute of Automation, Chinese Academy of Sciences, P.R. China); Bo Yang (Institute of Computing Technology, Chinese Academy of Sciences, P.R. China); Meng Zheng and Huaguang Shi (Shenyang Institute of Automation, Chinese Academy of Sciences, P.R. China); Seung Ho Hong (Hanyang University, Korea)

The limited spectrum resources inevitably incur the spectrum sharing among coexisting industrial wireless networks (IWNs), and multiple coexistence IWNs form a heterogeneous environment. An effective resource allocation thus plays a crucial role in coordinating the efficient operations of multiple IWNs. Existing works only study the constrained coexistence problem among specified types of networks with a limited number of nodes over one single channel. In this paper, we investigate a general coexistence problem over multiple channels among arbitrary types of networks with line topologies, and the number of nodes in each network is also arbitrary. We rigorously analyze the theoretical lower bound on scheduling latency of this general coexistence problem, then we propose an algorithm to attain the optimal result. The presented Coexisting Line topology Networks Resource Allocation (CLNRA) algorithm consists of two phases. In the inter-network resource allocation phase, non-overlapped channels are allocated to each network according to the corresponding transmission priority. While in the intra-network resource allocation phase, we filter out the nodes that may generate continuous empty buffers so as to enhance the resource utilization ratio. We also verify the effectiveness of the CLNRA algorithm through extensive simulations. Evaluation results show that the CLNRA algorithm can attain the optimal result in 99.3% cases, and it has obvious superiorities on resource utilization ratio and scheduling latency.
pp. 337-345

Joint Beamforming-Power-Bandwidth Allocation in Terahertz NOMA Networks

Xiaofei Zhang and Chong Han (Shanghai Jiao Tong University, P.R. China); Xudong Wang (Shanghai Jiao Tong University & Teranovi Technologies, Inc., P.R. China)

A downlink Terahertz NOMA (THz-NOMA) system with M beams is proposed in this paper, where each beam serves four users as a user cluster. Furthermore, two NOMA groups are grouped in each cluster. The Beamforming-Power-Bandwidth (B-P-B) problem is formulated aiming to maximize the network throughput while satisfying the QoS requirement of each user. Based on the THz-NOMA architecture and user distribution information, the beamforming design is first performed at base station (BS), in terms of the beam direction and the beamwidth. Then the B-P-B problem is

evolved to the Power-Bandwidth (P-B) resource allocation problem, which is of importance to exploit the full benefit of THz-NOMA system. The mixed integer P-B problem can be solved with the support of decomposition theory, which allows sub-band assignment to be conducted in each cluster, while allowing power allocation to be carried out in the cell. The Long-User-Central-Window (LUCW) peculiarity of THz is captured by the Hungarian algorithm to adaptively assign sub-band between NOMA groups of a user cluster. According to the LUCW principle, the central sub-band of a THz window is assigned to the long NOMA group, while the side sub-band unavailable at long NOMA group is allocated to the short NOMA group. Then an iterative algorithm is proposed to acquire the optimal power allocation. Simulation results show an improved sum rate performance of THz-NOMA, 928.4 Gbps can be achieved, compared with the OMA system. Furthermore, the effects of sub-band assignment coefficient and NOMA grouping scheme are investigated. The results indicate that the sub-band assignment coefficient is preferred to be set between 0.47 and 0.7. Moreover, the favored NOMA grouping scheme requires a larger distance difference.
pp. 346-354

Strategic Network Infrastructure Sharing through Backup Reservation in a Competitive Environment

Jing Hou, Li Sun and Tao Shu (Auburn University, USA); Yong Xiao (Huazhong University of Science and Technology, P.R. China); Marwan Krunz (University of Arizona, USA)
In transitioning to 5G, the high infrastructure cost, the need for fast rollout of new services, and the frequent technology/system upgrades triggered wireless operators to consider adopting the cost-effective network infrastructure sharing (NIS), even among competitors, to gain technology and market access. To collaborate with competitors, NIS is a bargain whose terms and conditions need to be carefully determined to guarantee profitability in a market with uncertainties. In this work, we propose a strategic NIS framework for contractual backup reservation between a small/local network operator of limited resources and uncertain demands, and one resourceful operator with potentially redundant capacity. The backup reservation agreement requires the local operator (say, operator A) to pay a fixed reservation fee to the resource-owning operator (say, operator B) at fixed time intervals. In return, the operator B guarantees availability of its resource (e.g., spectrum) up to a predetermined level. In such a way, a certain amount of backup resource capacity is reserved for future use under high traffic demand. We characterize the bargaining between the operators in terms of the optimal reservation prices and resource reservation quantities w/o considerations of the competitions between operators in market share. The conditions under which the competitive operators will cooperate are explored. The impacts of competition intensity, redundant capacity, and demand uncertainty on performance under backup reservation are also investigated. Our study shows that NIS through backup reservation leads to both higher resource utilization and profits for operators, as well as higher service levels for end users. We also find that, under certain conditions, operator B will share its resources with operator A even at the risk of impinging on its own users, and the impact of competition intensity on the sharing decisions is highly dependent on the amount of potential redundant capacity.
pp. 355-363

Tuesday, June 11 18:00 - 19:00

PD: Posters/Demos

Ultralow Power Wireless-Fire-Alarm-System using a VO2-Based Metal-Insulator-Transition Device

Jimin Son (University of Science and Technology & Electronics and Telecommunications Research Institute, Korea); Sungwoo Jo and Sun-kyu Jung (Electronics and Telecommunications Research Institute, Korea); Hyun-Tak Kim (University of Science and Technology & Electronics and Telecommunications Research Institute, Korea)

Low power consumption is important to a battery powered IoT fire alarm system. However, most other existing commercial wireless fire alarm system is difficult to reduce its power consumption, because Micro Controller Unit (MCU) wakes up from standby mode to working mode every few seconds to monitor ambient temperature whether fire occurs or not. Comparing with other wireless fire alarm system that has been already developed, "Wireless Metal Insulator Transition (MIT) Fire Alarm System" can dramatically lower power consumption by applying Critical Temperature Switch (CTS). "Wireless MIT Fire Alarm System" is comprised of a wireless communication module and a fire detection module. The CTS, playing a key role in fire detection module, is a heat sensor made of Vanadium dioxide (VO2). Due to the VO2's own property of MIT, when ambient temperature arrives at high temperature, the resistance of the CTS rapidly drops down more than 105 order. Therefore the CTS can always (not every few seconds) monitor ambient temperature, while the MCU becomes shutdown mode. In the shutdown mode, the MCU doesn't work with any of its other function including an Analog Digital Convertor (ADC) and only the CTS works to monitor as a sensing device. When the CTS has high resistance in ambient temperature, the MCU maintains shutdown mode. As the CTS changes into low resistance in case of fire breakout, the CTS makes the MCU change into working mode to make an alarm and wireless communication. Bluetooth Low Energy (BLE) is additionally applied to wireless communication module to support compatibility with mobile phone and low power consumption of "Wireless MIT Fire Alarm." BLE beacons can be monitored by supervisor from the webserver pages. In conclusion, the CTS control the MCU to activate only when it need to make a fire alarm and wireless communication. For this reason, the standby power consumption can be minimized.

pp. 364-365

Service Station Positioning for Mobile Charger in Wireless Rechargeable Sensor Networks

Yinan Zhu (Zhejiang University of Technology, P.R. China)

Near-field wireless power transfer has been widely used for powering sensor nodes in WSN, where mobile charger (MC) is employed to traverse the network. However, due to the limited energy of MC, MC needs to return to service station (SS) for replacing energy source for multiple times. Therefore, the location of SS directly determines the travelling distance of MC and the charging completion time as well. Motivated by this, we consider the SS positioning problem with jointly optimizing the charging tour of MC. We decompose it into two sub-problems and propose efficient algorithms to solve them based on a novel discretization method. Simulation results show the effectiveness of our design.

pp. 366-367

Implementing a Real-Time Image Captioning Service for Scene Identification Using Embedded System

He-Yen Hsieh (Academia Sinica, Taiwan); Jenq-Shiou Leu and Sheng-An Huang (National Taiwan University of Science and Technology, Taiwan)

Recently, home health care plays an important role in our life. People tend to utilize technologies to assist them in home health care. With the rapid development of wireless technologies and the Internet of Things (IoT), using a webcam to monitor the home remotely with mobile devices has been common recently. However, most people can not always use their mobile devices to know what happened in their house while working outside. Thus, we design a model to extract the semantic information of images captured from a webcam and translate the images into human-readable sentences. In this paper, we implement a real-time scene identification system using an image captioning model on an embedded system. The image captioning model can translate the image captured by a webcam installed on the embedded system into a human-readable sentence immediately. Users can get the information quickly by reading only the sentences. There are two stages in the image captioning model. First, a deep neural network extracts features from images captured from the webcam. Second, a long-short term memory generates the corresponding sentence. Due to the portability of the embedded system, our scene identification system can be placed anywhere at home or in the company. We evaluate the execution time in different aspects on several embedded systems and demonstrate the generated sentences from the captured images by our scene identification system.

pp. 368-369

Underwater Datalogger for Accurate Position and Location Estmation and Tracking

Xiyuan Zhu (LU, USA); Wurong Shih and Yahong Rosa Zheng (Lehigh University, USA)

With this demo, we show the design of an underwater datalogger that can achieve accurate position and location estimation and tracking on the order of centimeters. The prototype of underwater datalogger utilizes a 9-axis inertial measurement unit (IMU) and a microcontroller, which is housed in a sphere with a diameter of 2 cm. A novel calibration procedure is developed to achieve the accuracy and precision which is of great importance in civil engineering experiments that measure water flow and sediment movement.

pp. 370-371

A New Paradigm for Non-contact Vitals Monitoring using Visible Light Sensing

Hisham Abuella and Sabit Ekin (Oklahoma State University, USA)

Typical techniques for tracking vital signs require body contact and most of these techniques are intrusive in nature. Body-contact methods might irritate the patient's skin and he/she might feel uncomfortable while sensors are touching his/her body. In this study, we present a new wireless (non-contact) method for monitoring human vital signs (breathing and heartbeat). We have demonstrated for the first time that vitals signs can be measured wirelessly through visible light signal reflected from a human subject, also referred to as visible light sensing (VLS). In this method, the breathing and heartbeat rates are measured without any body-contact device, using only a simple photodetector (PD) and a light source (e.g., LED). The light signal reflected from human subject is modulated by the physical motions during breathing and heartbeats. Signal processing tools such as filtering and Fourier transform are used to convert these small variations in the received light signal power to vitals data. We implemented the VLS-based non-contact vital signs monitoring system by using an off-the-shelf light source, a PD and a signal acquisition and processing unit. We observed more than 90% of accuracy as compared to a contact-based FDA

(The Food and Drug Administration) approved devices. Additional evaluations are planned to assess the performance of the developed vitals monitoring system, e.g., different subjects, environments, etc. Non-contact vitals monitoring system can be used in various areas and scenarios such as medical facilities, residential homes, security and human-computer-interaction (HCI) applications.
pp. 372-373

MOSFET-based Ultra-low-power Realization of Analog Joint Source-Channel Coding for IoTs

Vidyasagar Sadhu, Mehdi Rahmati and Dario Pompili (Rutgers University, USA)

Certain sensing applications such as Internet of Things~(IoTs), where the sensing phenomenon may change rapidly in both time and space, require sensors that consume ultra-low power devices (so that they do not need to be put to sleep leading to loss of temporal and spatial resolution) and have low costs (for high density deployment). A novel encoding based on Metal Oxide Semiconductor Field Effect Transistors~(MOSFETs) is proposed to realize Analog Joint Source Channel Coding~(AJSCC), a low-complexity technique to compress two (or more) signals into one with controlled distortion. The approach is verified via Spice simulations and breadboard implementation.
pp. 374-376

Early Classification Approach for Multivariate Time Series using Sensors of Different Sampling Rate

Ashish Gupta (IIT(BHU), India); Hari Prabhat Gupta (Indian Institute of Technology (BHU) Varanasi, INDIA, India); Tanima Dutta (IIT (BHU) Varanasi, India)

Classification of Multivariate Time Series (MTS) data has been an important area of research for many years. In the time-critical applications, such as health informatics, fire detection, and disaster forecasting, it is desirable to classify the MTS data as early as possible. This work proposes an early classification approach to classify an incoming MTS. The early classification approach helps to predict the class label of an incoming MTS without waiting for full length. Different from the existing work, this work considers that sampling rate of the sensors which generated the MTS is different. The performance of the approach is evaluated on a publicly available dataset using accuracy, earliness and energy consumption.
pp. 377-378

An Adaptive Power level Allocation Model in LoRa for Internet of Things

Preti Kumari (IIT(BHU), India); Hari Prabhat Gupta (Indian Institute of Technology (BHU) Varanasi, INDIA, India); Tanima Dutta (IIT (BHU) Varanasi, India)

Internet of Things (IoT) finds their applications in many areas that include environmental monitoring, industrial control, traffic congestion control, smart metering, and smart parking. An important issue of research in IoT is to successfully transmit the data to the cloud and yet minimize the energy consumption of the battery-powered IoT devices. Long Rage (LoRa) is a long-range wireless communication protocol that competes against other low-power wide-area networks. In this paper, we propose a Stackelberg Game based model for allocation of the appropriate power levels to the LoRa nodes in energy efficient LoRa network. The utility of the network server, works as a leader player, is to successfully receive the data from the LoRa nodes. The utility of the LoRa nodes, work as followers player, is to reduce the power consumption during transmission of the data to the LoRa gateway. Simulation results evaluate the performance of the proposed game model to validate its effectiveness.
pp. 379-380

Long-Range Short-Burst Mobile Mesh Networking: Architecture and Evaluation

Ram Ramanathan, Christophe Servaes and Warren Ramanathan (GOTENNA, USA); Ayush Dusia and Adarshpal Sethi (University of Delaware, USA)

Decentralized off-grid short-burst communications for public safety and other applications require mobile wireless networks that can be inexpensively and instantly deployed to cover a large area. We present the networking architecture of goTenna -- a long-range lightweight device that forms a multi-hop mobile mesh network with other such devices. To maximize coverage, goTenna trades bit-rate for range. The resulting capacity is insufficient to support existing mesh networking protocols due to their excessive control overhead. We describe a novel zero-control-packet approach for broadcasting and unicasting that builds state by observing packet header information. We then describe its experimental evaluation using ns3, and on a goTenna testbed, concluding with some research challenges.

pp. 381-382

Wednesday, June 12

Wednesday, June 12 13:40 - 15:40

A3: Wearable/Cyber-Physical Systems

Chair: Dario Pompili (Rutgers University, USA)

MType: A Magnetic Field-based Typing System on the Hand for Around-Device Interaction

Yufeng Deng, Dong Wang, Qian Zhang and Run Zhao (Shanghai Jiao Tong University, P.R. China)

Smart wearable devices have become pervasive as they are portable and intelligent. The popular method to interact with it is touch-screen, which is error-prone and cumbersome due to its limited size. There are a few innovative works designing a virtual dial plate on the hand back, which need special purpose-sensors or microphones which may suffer from privacy leak. We propose MType, a system only employs sensors already built in the commercial-off-the-shelf (COTS) device with a magnetic ring to expand the interaction space between users and wearable devices. The core idea is to leverage the gravity sensor, linear accelerometer and magnetometer embedded in the standard smartwatch to detect gestures, capture input events and locate keystrokes on the opisthenar and palm. Besides, MType designs a runtime adaptation mechanism to handle the cold start problem and adapt to the variations over the time of usage. We implement MType on the COTS smartwatch and our extensive experiments in different scenarios show that the average accuracy of keystroke localization can reach 93% with a small size initial training set (3 samples for each key) at a low sampling rate (51Hz). Furthermore, when turning on the runtime adaptation mechanism and enlarging the training set size, the accuracy can achieve 98%.

pp. 383-391

Quality of Control Assessment for Tactile Cyber-Physical Systems

Kurian Polachan (Indian Institute of Science, India); T Venkata Prabhakar (IISc, India); Chandramani Singh (Indian Institute of Science, India); Deepak Panchapakesan (Indian Institute of Science, USA)

In this paper, we evolve a methodology and define a metric to evaluate Tactile Cyber-Physical Systems (TCPS). Towards this goal, we adopt the step response analysis, a wellknown control theoretic method. The adoption includes replacing the human operator (or master) with a controller with known characteristics and analyzing its response to slave side haptic sensor step changes. The

resulting step response curves demonstrate that the Quality of Control (QoC) metric is sensitive to control loop instabilities and serves as a good indicator of cybersickness experienced by human operators. We demonstrate the efficacy of the proposed methodology and metric through experiments on a TCPS testbed. The experiments include assessing the suitability of several access technologies, intercontinental links and testbed configurations.
pp. 392-400

DeepLap: A Deep Learning based Non-Specific Low Back Pain Symptomatic Muscles Recognition System

Nian Wang and Zhe Zhang (Institute of Computing Technology, Chinese Academy of Sciences & University of Chinese Academy of Sciences, P.R. China); Jing Xiao (Xiyuan Hospital, China Academy of Chinese Medical Sciences, P.R. China); Li Cui (Institute of Computing Technology, Chinese Academy of Sciences, P.R. China)

As sedentary and inactivity lifestyles are becoming increasingly common among humans, non-specific low back pain (nLBP) has gradually become an epidemic. It is necessary to recognize and locate symptomatic muscles which can be used to personalize the treatment. However, the existing symptomatic muscles recognition methods highly depend on physicians experience and lack objective criterions. And most of the diagnostic methods using biomedical signal, such as surface electromyography (sEMG), can only distinguish patients from normal people. The only system that recognizes symptomatic muscles suffers from low accuracy problem because it uses the handcrafted features. In this paper, we propose DeepLap, a deep learning based non-specific low back pain symptomatic muscles recognition system. It first extracts time and frequency domain sEMG from the raw sEMG signal. Then a heterogeneous two-stream multi-task deep learning algorithm is deployed, which processes the two inputs separately according to their characteristics. Moreover, in order to improve the recognition accuracy and take the muscles compensation information into account, we design a multi-task neural network and propose the Spanning CNN. Finally, we design and implement a waist-belt-shaped wireless sEMG sensing and analysis system to validate the performance of our system, which runs successfully for 28 months on 288 participants in (Anonymous) Hospital. Results show that DeepLap achieves an average accuracy of 92.9% in recognizing symptomatic nLBP low back muscles.
pp. 401-409

Speech Based Human Authentication on Smartphones

Haipeng Dai (Nanjing University & State Key Laboratory for Novel Software Technology, P.R. China); Wei Wang (Nanjing University, P.R. China); Alex X. Liu (Michigan State University, USA); Kang Ling and Jiajun Sun (Nanjing University, P.R. China)

Voice has been used as biometrics for human authentication because different people have different voice characteristics due to different vocal tract shapes and intonations. However, traditional voice based human authentication is subject to four types of attacks: impersonation, voice conversion, synthesis and voice replay. In this paper, we propose SpeakPrint, an ultrasound based human speech authentication scheme for smartphones which is resistant for these attacks. Compared with traditional speech authentication system which focuses on what a user speaks, SpeakPrint captures how a user speaks by recording mouth and vocal movement through ultrasound signal at the same time. Our key insight is that for the valid user, features extracted from voice signal should be consistent with his mouth and vocal movement recorded from ultrasound signal, while an imitator or an audio player can't produce the same signals in ultrasound domain. SpeakPrint extracts MFCC feature in normal voice frequency and MMSI features from ultrasound signal. An SVM classifier is

trained to detect these attacks by comparing above feature differences. We implemented SpeakPrint on Samsung S5 and conducted experiments on 40 users. Experimental results show that SpeakPrint can detect replay attacks with 100% accuracy and replay attack with lip synching for 99.12% for passphrases longer than five words. This technology can be used in multi-factor authentication systems, where multiple authentication mechanisms are used to achieve defense in depth.
pp. 410-418

FaceInput: A Hand-Free and Secure Text Entry System through Facial Vibration

Maoning Guan, Wenqiang Chen, Yandao Huang, Rukhsana Ruby and Kaishun Wu (Shenzhen University, P.R. China)

Wearable wristbands have become prevailing in the recent days because of their small and portable property. However, the limited size of the touch screen causes the problems of fat fingers and screen occlusion. Furthermore, it is not available for users whose hands are fully occupied with other tasks. To break this bottleneck, we propose a portable, hand-free and secure text-entry system, called FaceInput, which firstly uses a single small form factor sensor to accomplish a practical user input via facial vibrations. To sense the tiny facial vibration signals, we design and implement a double-stage amplifier whose maximum gain is 225. To enhance the input accuracy and robustness, we design a set of novel schemes for FaceInput based on the Mel-frequency cepstral coefficient (MFCC) concept and a hidden Markov model (HMM) to process the vibration signals, and an online calibration and adaptation scheme to recover the error due to temporal instability. Extensive experiments have been conducted on 30 human subjects during the period of one month. The results demonstrate that FaceInput can be successful to sense the tiny facial vibrations and robust to fight against various confounding factors. The average recognition accuracy is 98.2%. Furthermore, by enabling the runtime calibration and adaptation scheme that updates and enlarges the training data set, the accuracy can reach 100%.
pp. 419-427

B3: Security & Privacy

Chair: Xiaowen Gong (Auburn University, USA)

Privacy-Preserving Sketching for Online Social Network Data Publication

Tianchong Gao and Feng Li (Indiana University-Purdue University Indianapolis, USA)

Releasing private data can cause panic to both Online Social Network (OSN) users and service providers. Therefore, anonymization mechanisms are proposed to protect data before sharing it. However, some of these mechanisms set unrealistic privacy demands but cannot defend against real-world de-anonymization attacks. In this paper, we introduce an anonymization algorithm based on All-Distance Sketch (ADS). Sketching can significantly limit attackers' confidence, as well as provide accurate estimation about shortest path length and other utility metrics. Because sketching removes large amounts of edges, it is invulnerable to seed-based and subgraph-based de-anonymization attacks. However, existing sketching algorithms do not add dummy edges and paths. Adversaries have low false positive in extracting linking information, which challenges the privacy performance. We propose the novel bottom-(l,k) sketch to defend against these advanced attacks. We develop a scheme to add and delete enough edges to satisfy our privacy demand. The experiment results show that our published graphs are closely matched with the original graphs under some metrics, preserving utility, while 80% edges are removed, ensuring privacy.
pp. 428-436

Towards Fast and Reliable WiFi Authentication by Utilizing Visible Light Diversity

Zhiwei Zhao (University of Electronic Science and Technology of China, P.R. China); Geyong Min (University of Exeter, United Kingdom (Great Britain)); Yaoyao Pang (UESTC, P.R. China); Weifeng Gao (University of Electronic Science and Technology of China, P.R. China); Jiamei Lv (Zhejiang University, P.R. China)

The openness of indoor WiFi networks makes it prone to spoofing attacks and password leakage/ sharing, where undesired users may be able to access the network resources. The fundamental reason is that the actual communication range is much larger than the valid authentication range, leaving undesired users the same chance to access the network from invalid authentication ranges. The existing works exploit various features of wireless signals to identify the legitimate/undesired users. However, these works either rely on frequent measurement and learning on the signal features or require the modification of the access point (AP) devices. In this paper, we identify visible light (VL) as a good indicator to distinguish the positions of the accessing users due to its frequency diversity. Based on this observation, we propose VL-Auth, a novel Authentication framework based on VL for indoor WiFi networks, which uses the VL features as credentials to authenticate WiFi users. VL-Auth can be easily installed on commercial-off-the-shelf (COTS) devices and do not require frequent measurement or learning of the VL features. We implement VL-Auth with OpenWrt and Android devices. The evaluation results show that compared to the existing works, VL-Auth can identify the legitimate/undesired users more accurately and the connection delay is also reduced.

pp. 437-445

ActiveTracker: Uncovering the Trajectory of App Activities over Encrypted Internet Traffic Streams

Ding Li, Wenzhong Li and Xiaoliang Wang (Nanjing University, P.R. China); Cam-Tu Nguyen (Nanjing University, Vietnam); Sanglu Lu (Nanjing University, P.R. China)

Despite the increasing popularity of mobile applications and the widespread adoption of encryption techniques, mobile devices are still susceptible to security and privacy risks. In this paper, we propose ActiveTracker, a new type of sniffing attack that can reveal the fine-grained trajectory of user's mobile app usage from a sniffed encrypted Internet traffic stream. It firstly adopts a sliding window based approach to divide the encrypted traffic stream into a sequence of segments corresponding to different app activities. Then each traffic segment is represented by a normalized temporal spacial traffic matrix and a traffic spectrum vector. Based on the normalized representation, a deep neural network (DNN) classification algorithm is developed to recognize the crucial activities conducted with different apps by the user. We show by extensive experiments on real-world app usage traffic collected from volunteers that the proposed approach achieves up to 78.5% accuracy in recognizing app trajectory over encrypted traffic streams.

pp. 446-454

Integrity Threat Identification for Distributed IoT in Precision Agriculture

Ravishankar Chamarajnagar (VMWare, USA); Ashwin Ashok (Georgia State University, USA)

Internet-of-Things (IoT) paradigms have created, in addition to opportunities, a huge void in security. Although there are multiple works that explore security through device identification, cryptography and network security protocols, the question of can we trust the integrity of things to represent reality or precisely, can we trust the data and the metrics being sent by things, remains largely unanswered in distributed wireless scenarios. Given how nascent the domain is and the rapid pace at which IoT is being adopted, ensuring that the data from each of these devices is trustable is

very challenging. Moreover, the problem becomes harder in wireless sensor network scenario, especially in harsh environments, due to the potential avenues for spoofing and physical attacks. To this end, this paper explores conditions or threat vectors under which a wireless network of devices may become unreliable in a fully distributed setting, and present an approach to identify potential integrity failures or threats. We present the effectiveness of our approach through a use-case analysis for precision agriculture applications. Through experimental and trace-based simulations, we show that threats can potentially be identified in real-time with 80% accuracy and at about 90% precision and recall.
pp. 455-463

Wide-Area GPS Time Monitoring Against Spoofing Using Belief Propagation
Sriramya Bhamidipati (UIUC, USA); Kyeong Jin Kim (Mitsubishi Electric Research Laboratories (MERL), USA); Hongbo Sun and Philip Orlik (Mitsubishi Electric Research Laboratories, USA)
A wide-area time authentication algorithm is proposed to compute the Global Positioning System (GPS) timing that is resilient against spoofing attacks. The considered wide-area network consists of multiple GPS receiving systems, each comprising of the innovative distributed multiple directional antennas (DMDA) setup triggered via a common clock. Based on the communication infrastructure of the grid, the single-difference pseudorange residuals across the antennas are processed using the wide-area belief propagation-based extended Kalman filter (BP-EKF) algorithm in a distributed manner. To detect spoofing, a KL-divergence-based threshold is used to estimate the dissimilarity in the antenna-specific timing errors. Thereafter, the pseudoranges are corrected using the BP estimates of timing error and processed via adaptive EKF to compute the GPS timing, which is given to the phasor measurement units (PMUs). We have demonstrated the successfully detection and mitigation of the external timing attack, by subjecting one receiving system to a simulated meaconing attack that induces a 60 micro second time delay. Thereafter, by analyzing the voltage stability index of a critical node in the simulated grid, we have also validated the compliance of the proposed wide-area BP-EKF estimated timing with the IEEE-C37.118 standards.
pp. 464-471

Wednesday, June 12 16:00 - 18:00

A4: Energy Efficient Systems

Chair: Mehdi Rahmati (Rutgers University, USA)

Pharos: A Rapid Neighbor Discovery Algorithm for Power-Restricted Wireless Sensor Networks
Yuchen Zhu, Bo Yang, Min Liu and Zhongcheng Li (Institute of Computing Technology, Chinese Academy of Sciences, P.R. China)
As it is difficult for power-restricted wireless sensor nodes to achieve rapid neighbor discovery under the scenarios of asynchronous clocks, misaligned time slots, and asymmetric duty-cycle (i.e., wake-up/sleep) scheduling periods, we propose a low-power neighbor discovery algorithm termed Pharos by alternately utilizing the fully and the partially awake time slots. The partially awake time slots of one node are certain to detect the counterpart's awake slots while reducing the power consumption as compared to the fully awake time slots. We analyze the theoretical neighbor discovery latency and derive the optimal parameter selection for the asymmetric duty-cycle schedule. We also verify the effectiveness of the Pharos algorithm through extensive simulations. Evaluation results display that Pharos costs much less discovery latency and power than the state-

of-the-art neighbor discovery algorithms.
pp. 472-480

When Wireless Charging Meets Fresnel Zones: Even Obstacles Can Enhance Charging Efficiency

Chi Lin and Feng Gao (Dalian University of Technology, P.R. China); Haipeng Dai (Nanjing University & State Key Laboratory for Novel Software Technology, P.R. China); Lei Wang and Guowei WU (Dalian University of Technology, P.R. China)

Benefitting from the discovery of wireless power transfer (WPT) technology, the wireless rechargeable sensor network (WRSN) becomes a promising way for lifetime extension for wireless sensor networks. However, in practical applications, obstacles can be found almost everywhere throughout the WRSN system. Most prior arts believe that obstacles will always degrade signal strength, they omit such influences for computation simplicity, which contradicts to the instincts of signal propagation, yielding their methods unsuitable for realistic adoptions. In this paper, we explore the wireless signal propagation process and provide a theoretical charging model to enhance charging efficiency by leveraging obstacles. Through utilizing the concept of the Fresnel Zones (FZs), we re-formalize the wireless charging model and discretize charging power to determine the best charging spots as well as charging durations. We model such charging efficiency maximization with obstacles (EMO) problem as a submodular function maximization problem and propose a cost-efficient algorithm with approximation ratio \(\frac{(e-1)}{e}(1-\epsilon)\) to solve it. Finally, test-bed experiments and simulations are conducted to verify that our schemes outperform comparison algorithms by at least 10% in charging efficiency improvement.
pp. 481-489

Parallel Feedback Communications for Magnetic MIMO Wireless Power Transfer System

Wenxiong Hua, Xiang Cui, Hao Zhou, Panlong Yang and Xiang-Yang Li (University of Science and Technology of China, P.R. China)

Receiver (RX) feedback and power transfer channel estimation are essential for enhancing the context-aware ability for magnetic resonant coupling (MRC) enabled wireless power transfer (WPT) systems. High efficient solutions are still immature in MIMO scenarios. In this work, we investigate the concurrent feedback communications for multiple RXs equipped with oscillating circuits. We discover an interesting clustering phenomenon, where the TX currents form clusters in corresponding to the combined RX "Open-Short" states. Based on this, we propose a parallel multi-stage decoding scheme by identifying the combined state for each cluster. In symbol clustering stage, we introduce two-layer clustering mechanism to tackle the "dominant RXs" challenge which causes inaccurate classification results. In cluster identification stage, we solve the "ambiguous identification candidates" challenge by calibration based on power transfer channel condition estimation. We have implemented the prototype testbed using off-the-shelf components. Our experiment results demonstrate the effectiveness of the proposed scheme. Our system provides valid communication distance up to 1 meter even under significant interference from other RX. The simulation results further suggest the scalability of the proposed scheme, and the accuracy for power transfer channel estimation.
pp. 490-498

No Entry: Anti-Noise Energy Detector for Chirp-Based Acoustic Communication

Chulyoung Kwak (Seoul National University, Korea); Seongwon Kim (SK Telecom, Korea); Soonwon Ka (Soundlly, Inc., Korea); Jihwan Lee and Sunghyun Choi (Seoul National University, Korea)

Acoustic communication using microphones and speakers of smart devices is one of the most

spotlighted wireless technologies in recent years. In particular, chirp-based acoustic communication is widely adopted for smart device applications because of its robustness to frequency selectivity. Since many chirp-based acoustic applications run in the background on mobile devices, the power consumption of chirp-based acoustic communication is a critically important issue. Using energy detectors (EDs), which determine the existence of a valid acoustic signal based on energy level, applications can reduce power consumption by working only when a valid signal exists. However, conventional ED fails to distinguish between valid signals and high-energy noise in everyday life. In this paper, we propose No Entry, a novel ED for chirp-based acoustic communication systems. No Entry avoids not only high-energy noises but also a different modulation-based acoustic signal by utilizing the frequency sweeping characteristic of chirp signals. We implement prototype Android applications to evaluate the detection accuracy and power consumption. Compared with the state-of-the-art schemes, No Entry reduces energy consumption by 30\% while achieving a greater detection performance.
pp. 499-507

NB-IoT Network Monitoring and Diagnosing

Zhenxian Hu, Guangtao Xue, Yi-Chao Chen and Minglu Li (Shanghai Jiao Tong University, P.R. China)

NarrowBand-IoT (NB-IoT) is a radio access technology standardized by 3GPP to support a large set of use cases associated with the rapid deployment of massive machine-type communications. NB-IoT facilitates the connection of devices in inaccessible areas, extends battery life, and reduces device complexity. Unfortunately, the opacity of the underlying schema (i.e., the way that these benefits are achieved) makes it very difficult for most users and developers to manage deployment scenarios. In this study, we built an embedded system comprising a Raspberry Pi with an NB module, referred to as NBPilot, which interacts with NB networks to identify essential signalling messages transmitted by a Qualcomm NB modem. This system gives researchers and developers an unprecedented understanding of network behaviour as well as the ability to adjust them to their particular requirements. We employed the-state-of-art machine learning techniques for modeling and the analysis of NB performance. The efficacy of the proposed NBPilot system was established by applying it to a metropolitan NB-IoT system with over 2,000 NB sites for the collection and testing of data trace as well as the validation of a cellular station prior to going online.
pp. 508-516

B4: Multimedia Analytics and Applications

Chair: Francesco Restuccia (Northeastern University, USA)

FoVR: Attention-based VR Streaming through Bandwidth-limited Wireless Networks

Songzhou Yang and Yuan He (Tsinghua University, P.R. China); Xiaolong Zheng (Beijing University of Posts and Telecommunications, P.R. China)

Consumer Virtual Reality (VR) has been widely used in various application areas, such as entertainment and medicine. In spite of the superb immersion experience, to enable high-quality VR on untethered mobile devices remains an extremely challenging task. The high bandwidth demands of VR streaming generally overburden a conventional wireless connection, which affects the user experience and in turn limits the usability of VR in practice. In this paper, we propose FoVR, attention-based hierarchical 360° video streaming through bandwidth-limited wireless networks. The design of FoVR stems from the insight that human's vision is hierarchical, so that different areas in the field of view (FoV) can be served with VR content of different qualities. By exploiting

the gaze tracking capacity of the VR devices, FoVR is able to accurately predict the users attention so that the streaming of hierarchical VR can be appropriately scheduled. In this way, FoVR significantly reduces the bandwidth cost and computing cost while keeping high quality of user experience. We implement FoVR on a commercial VR device and evaluate its performance in various scenarios. The experiment results show that FoVR reduces the bandwidth cost by 88.9% and 76.2%, respectively compared to the original VR streaming and the state-of-the-art approach.
pp. 517-525

Towards Scalable Video Analytics at the Edge

Theodore Stone and Nathaniel Stone (University of South Carolina, USA); Puneet Jain (Google, USA); Yurong Jiang (HP Labs, USA); Kyu-Han Kim (Hewlett-Packard Laboratories, USA); Srihari Nelakuditi (University of South Carolina, USA)

Breakthroughs in deep learning, GPU, and edge compute have paved the way for always-on, real-time video analytics. Convolutional neural networks (CNNs) now allow most computer vision tasks to be performed accurately and efficiently. However, to achieve real-time performance, a GPU needs to be dedicated amongst a few video feeds. Given that GPUs are expensive resources and a large-scale deployment requires supporting hundreds of video cameras -- exorbitant cost prohibits widespread adoption. To ease this burden, we propose Tetris, a system comprising of several optimization techniques from computer vision and deep-learning literature blended in a synergistic manner. Tetris is designed to maximize the parallel processing of video feeds on a single GPU, with a marginal drop in inference accuracy. Tetris performs CPU-based active region segmentation and bin-packing to combine activities across video feeds, resulting in a condensed input volume. It then runs the deep learning model on the condensed volume instead of individual feeds, which significantly improves the GPU utilization. Our evaluation on Duke MTMC dataset reveals that Tetris can process 4x video feeds in parallel compared to any isolated method in the state-of-the-art.
pp. 526-534

Truthful Quality-Aware Data Crowdsensing for Machine Learning

Yuxi Zhao and Xiaowen Gong (Auburn University, USA)

Crowdsensing has found a broad range of applications (e.g., spectrum sensing, environmental monitoring) by leveraging the ``wisdom'' of a potentially large crowd of ``workers'' (i.e., mobile users). One important class of applications use the data collected from crowdsensing for data analytics via machine learning. To exploit the potential of crowdsensing for machine learning, it is beneficial to for the crowdsensing requester to know and make use of the quality of worker's data. In this paper, based on a general linear regression model of machine learning, we devise truthful quality-aware crowdsensing mechanisms for quality and effort elicitation, which incentivize workers to truthfully report their private worker quality to the requester, and make effort as desired by the requester. The truthful design of the mechanisms overcomes different and unknown ground truths of workers' tasks and the coupling in the joint elicitation of worker quality, effort, and data. Under the mechanisms, we characterize the socially optimal and the requester's optimal effort assignments, and analyze their performance. We show that the requester's optimal assignment is determined by the ``virtual quality'' rather than the highest quality among workers, which depends on the worker's quality and the quality's distribution. Simulation results are provided which demonstrate the truthfulness of the mechanisms and the performance of the optimal effort assignments.
pp. 535-543

Workload-Aware Task Placement in Edge-Assisted Human Re-identification

Anil Acharya and Yantian Hou (Boise State University, USA); Ying Mao (Fordham University, USA); Min Xian (University of Idaho, USA); Jiawei Yuan (Embry-Riddle Aeronautical University, USA)

This work is a cross-domain study by utilizing the most recent cloud/edge computing techniques in the human re-identification, which is a popular computer-vision application motivated by the practical demand of connecting and monitoring our world in the era of Internet of things (IoT). We systematically study the real-time re-identification problem within a large-scale video surveillance network. Motivated by the system heterogeneity in terms of real-time workload and hardware configurations, we develop a workload-aware distributed system, which optimally allocates tasks across edge servers and cloud, in pursuing a user-controlled trade-off between system responsiveness & utility. We use an experiment-oriented approach to measure and model the edge heterogeneity. A two-phase task-placement algorithm is proposed which runs with the models built in off-line phase,and driven by the dynamic real-time workload in runtime. We implement our entire system on commercial cloud platform and use extensive simulations and experiments to validate its efficacy in practice.

pp. 544-552

Enabling Secure Voice Input on Augmented Reality Headsets using Internal Body Voice

Jiacheng Shang and Jie Wu (Temple University, USA)

Voice-based input is usually used as the primary input method for augmented reality (AR) headsets due to immersive AR experience and good recognition performance. However, recent researches have shown that an attacker can inject inaudible voice commands to the devices that lack voice verification. Even if we secure voice input with voice verification techniques, an attacker can easily "steal" the victim's voice using low-cast handy recorders and replay it to voice-based applications. To defend against voice-spoofing attacks, AR headsets should be able to determine whether the voice is from the person who is using the AR headsets. Existing voice-spoofing defense systems are designed for smartphone platforms. Due to the special locations of microphones and loudspeakers on AR headsets, existing solutions are hard to be implemented on AR headsets. To address this challenge, in this paper, we propose a voice-spoofing defense system for AR headsets by leveraging both the internal body propagation and the air propagation of human voices. Experimental results show that our system can successfully accept normal users with an average accuracy of 97% and defend against two types of attacks with average accuracy of at least 98%.

pp. 553-561

Thursday, June 13

Thursday, June 13 10:30 - 12:30

A5: Networked Robotics

Chair: Xuyu Wang (California State University, Sacramento, USA)

Maximizing Energy Efficiency of Period-Area Coverage with UAVs for Wireless Rechargeable Sensor Networks

Chi Lin and Chunyang Guo (Dalian University of Technology, P.R. China); Wan Du (University of California, Merced, USA); Jing Deng (University of North Carolina at Greensboro, USA); Lei Wang and Guowei WU (Dalian University of Technology, P.R. China)

Wireless Rechargeable Sensor Networks (WRSNs) with perpetual network lifetime have been used in many Internet of Things (IoT) applications, like smart city and precision agriculture. Rechargeable sensors together with Unmanned Aerial Vehicles (UAVs) are collaboratively employed for fulfilling periodic coverage tasks. However, traditional coverage solutions are normally based on static deployment of sensors and not suitable for such coverage requirements. In this paper, we propose a new concept of coverage problem named Period-Area Coverage (PAC) which requires data of the overall area must be collected periodically. We focus on maximizing the energy efficiency of UAVs and propose two heuristic scheduling schemes to balance energy cost. Moreover, we adopt adjustable sensing range to further promote efficiency and develop a charging re-allocation mechanism for UAVs. Test-bed experiments and extensive simulations demonstrate that the proposed schemes can enhance energy efficiency by 18.2 compared to prior arts.
pp. 562-570

VISIT: Placement of Unmanned Aerial Vehicles for Anisotropic Monitoring Tasks

Weijun Wang (Nanjing University, P.R. China); Haipeng Dai (Nanjing University & State Key Laboratory for Novel Software Technology, P.R. China); Chao Dong (Nanjing University of Aeronautics and Astronautics, P.R. China); Fu Xiao (Nanjing University of Posts and Telecommunications, P.R. China); Xiao Cheng (Nanjing University, P.R. China); Guihai Chen (Shanghai Jiao Tong University, P.R. China)

This paper considers the fundamental problem of placement of Unmanned Aerial VehIcles for aniSotropic monItoring Tasks (VISIT). That is, given a set of objects on 2D area, place a fixed number of UAVs by adjusting their coordinates and orientations subject to Gaussian bias, such that the overall monitoring utility for all objects is maximized. We develop a theoretical framework to address VISIT. First, we establish the monitoring model whose quality of monitoring (QoM) is anisotropy with respect to monitoring angle and monitoring distance. To the best of our knowledge, we are the first to consider anisotropic QoM. Then, we propose an algorithm consisting of area discretization and Monitoring Dominating Set (MDS) extraction, to reduce the infinite solution space to a limited one without performance loss. Finally, we prove that the reformulated problem can be modeled as maximizing a monotone submodular function subject to a matroid constraint and present a greedy algorithm with 1-1/e-\epsilon approximation ratio to address it. We conduct both simulations and field experiments to evaluate our algorithm, and the results show that our algorithm outperforms comparison algorithms by at least 41.3%.
pp. 571-579

Decentralized Task Allocation in Lossy Networks: A Simulation Study

Nicholas Mastronarde (University at Buffalo, USA); Karthik Dantu (University of Buffalo, USA); Matthew Rantanen (University at Buffalo, USA); Jeffrey Hudack (Air Force Research Laboratory, USA)

Advances in hardware, software and sensing are bringing swarms of robots to daily life for cleaning urban spaces, assisting in hospitals, helping first responders, and more. A major challenge in enabling such applications is multi-robot coordination. Most multi-robot coordination algorithms are developed under the assumption of perfect communication, which does not hold in practical wireless networks. To understand the consequences of this, we investigate the performance of a representative task allocation algorithm for multi-robot systems, namely, the Asynchronous Consensus Based Bundle Algorithm (ACBBA), in realistic network conditions. We show that the ACBBA deviates from its desired theoretical behavior when deployed in a realistic network. This manifests in the form of redundant task assignments across agents, which violates the algorithm's

"conflict-free" task assignment constraint and degrades the task allocation efficiency. We explore several network-based mitigations to this problem.
pp. 580-588

FusionEye: Perception Sharing for Connected Vehicles and its Bandwidth-Accuracy Trade-offs

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Automated driving and advanced driver assistance systems benefit from a complete understanding of the traffic scene around a vehicle. Existing systems gather such data through cameras and other sensors in vehicles but scene understanding can be limited due to the sensing range of sensors or occlusion from other obstacles and traffic. To gather information beyond the view of one vehicle, we propose and explore FusionEye, a connected vehicle system that allows multiple vehicles to share perception data over vehicle-to-vehicle communications and then collaboratively merges this data into a more complete traffic scene. FusionEye uses a self-adaptive topology merging algorithm based on bipartite graph. We explore its network bandwidth requirements and the trade-off with merging accuracy. Experimental results show that FusionEye creates more complete scenes and achieves a merging accuracy of 88% with 5% packet drop rate and transmission latency around 200ms. We show that richer vehicle descriptors offer only marginal accuracy improvements compared to lower communication overhead options.
pp. 589-597

ECO-UW IoT: Eco-friendly Reliable and Persistent Data Transmission in Underwater Internet of Things

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Achieving reliable and persistent environmental field estimation in the context of Underwater Internet of Things (UW IoT) is still a challenging problem due to the limited-bandwidth and error-prone acoustic channel as well as the harsh and unpredictable underwater environment. Given the need for high-resolution spatio-temporal sensing in such environment, traditional digital sensors are not suitable due to high costs, high power consumption, and non-biodegradable nature. Further, reliable communication techniques that avoid costly retransmissions are crucial for reconstructing the phenomenon in a timely manner at the fusion center such as a drone. To address the above challenges, we propose a novel architecture consisting of a substrate of densely deployed underwater all-analog biodegradable sensors that continuously transmit data to the surface digital buoys. The analog nodes are designed to be energy efficient by implementing Analog Joint Source Channel Coding (AJSCC), a low-complexity compression-communication technique, using biodegradable Field Effect Transistors (FETs). We then propose a correlation-aware Hybrid Automatic Repeat Request (HARQ) technique to transmit data from the surface buoys to the fusion center. The proposed HARQ technique leverages the correlation in the buoy data (arising from the correlation of the phenomenon at the analog nodes) to avoid costly retransmissions, thus saving energy and time. The performance of the proposed analog sensor design and of the correlation-aware HARQ communication technique has been evaluated via simulations and shown to achieve the desired behavior.
pp. 598-606

B5: Edge/Fog Computing

Chair: Emad H. Aboelela (Northeastern University, USA)

Dependency-Aware and Latency-Optimal Computation Offloading for Multi-User Edge Computing Networks

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With the various emerging innovative applications such as virtual reality, the Internet-of-Things (IoT) systems are expected to fulfill more computation-intensive and latency-sensitive sensing and computational tasks, which poses huge challenges for the IoT systems as IoT devices have limited computational ability and battery capacity. To address this problem, edge computing is a promising architecture where the IoT devices can offload their tasks to the edge servers. However, the existing works on task offloading often overlook the unique task topologies and schedules from the IoT devices, leading to degraded performance and under-utilization of the edge resources. In this paper, we investigate the problem of fine-grained task offloading in edge computing for low-power IoT systems. By explicitly considering 1) the topology/schedules of the IoT tasks, 2) the heterogeneous resources on edge servers and 3) the wireless interference in the multi-access edge networks, we propose a lightweight yet efficient offloading scheme for multiuser Edge systems, which offloads the most appropriate IoT tasks to edge servers such that the expected execution time is minimized. Both centralized and game-theory based distributed algorithms are devised in order to support sparse and dense network scenarios. We conduct extensive simulation experiments and the results show that the proposed offloading algorithms can effectively reduce the end-to-end task execution time and improve the resource utilization of the edge servers.

pp. 607-615

COSTA: Cost-aware Service Caching and Task Offloading Assignment in Mobile-Edge Computing

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This paper considers a Mobile-Edge Computing~(MEC) enabled wireless network where the MEC-enabled Base Station (MBSs) can host application services and execute computation tasks corresponding to these services when they are offloaded from resource-constrained mobile users. We aim at addressing the joint problem of service caching---the provisioning of application services and their related libraries/database at the MBSs---and task-offloading assignment in a densely-deployed network where each user can exploit the degrees of freedom in offloading different portions of its computation task to multiple nearby MBSs. Firstly, an offloading cost model is introduced to capture the user energy consumption, the service caching cost, and the cloud usage cost. The underlying problem is then formulated as a Mixed-Integer Linear Programming (MILP) problem, which is shown to be NP-hard. Given the intractability of the problem, we exploit local-search techniques to design a polynomial-time iterative algorithm, named COSTA. We prove that COSTA produces a locally optimal solution with cost of at most a constant approximation ratio compared to the optimum. Trace-driven simulations using the workload records from a Google cluster show that COSTA can significantly reduce the offloading cost over competing schemes while achieving a very small optimality gap.

pp. 616-624

InDP: In-Network Data Processing for Wireless Sensor Networks

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Wireless sensor networks have emerged as an important information collection and monitoring tool. However, the approach of forwarding all the sensed data to a sink for processing is not always practical due to the high communication cost. In this paper, we present InDP, a framework that is designed to support data dissemination and processing in the edge. InDP has a communication component and a computation component. The communication component supports a low duty cycle mode for an infrequent status update and a high throughput mode to support distributed computation. The computation component implements a distributed version of Principal Component Analysis (PCA). As an application, we have implemented an outlier detection component over InDP. InDP and the outlier detection application have been implemented on Contiki using a modified version of Codecast as the underlying many-to-many communication protocol. Our evaluations show that InDP can terminate as fast as 100ms and 1.3s on the average running on a testbed with more than 70 nodes. In terms of PCA computation, InDP's computation uses 91.6% less data than a centralized approach and is able to detect anomalies using a fraction of the sensed data.

pp. 625-633

Driving in the Fog: Latency Measurement, Modeling, and Optimization of LTE-based Fog Computing for Smart Vehicles

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Fog computing has been advocated as an enabling technology for computationally intensive ultra-low latency services in smart vehicles. Most existing works focus on analyzing and optimizing the queueing and workload processing latencies, ignoring the fact that the access latency between vehicles and fog/cloud servers can sometimes dominate the end-to-end service latency. This motivates the work in this paper, where we report a five-month urban measurement study of the wireless access latency between a moving vehicle and a fog computing system that is connected through a multi-operator LTE system. Based on these extensive measurements, we propose AdaptiveFog, a novel framework for autonomous and dynamic switching between different LTE operators that implement fog/cloud infrastructure. The main objective here is to maximize the service confidence level, defined as the probability that a given latency threshold is not exceeded for each service request. AdaptiveFog was implemented on a smart phone app, running on a moving vehicle. The app periodically measures the round-trip latency between the vehicle and fog/cloud servers. An empirical spatial statistic model is established to characterize the spatial variation of latency across various locations in the city. To quantify the performance difference between different LTE networks, we use the weighted Kantorovich-Rubinstein (K-R) distance. An optimal policy is derived for the vehicle to decide the optimal LTE network while driving. Extensive analysis and simulation are performed based on our latency measurement dataset. Our results show that AdaptiveFog achieves around 30% and 50% improvement in the confidence level of fog node and cloud latency, respectively.

pp. 634-642

Network Function Deployment with Balanced Server and Link Resources in Tree Topologies

Yang Chen and Jie Wu (Temple University, USA)

Network Function Virtualization (NFV) decouples network functions from dedicated hardware elements into software middleboxes, resulting in significant reduction of management cost in

network service provisioning. Multiple flows serving flows in a specific order, is called a service chain. Deploying service chains on switch-connected servers in networks are challenging, because of not only multiple available servers, but also traffic-changing effects of middleboxes. This paper formulates the resource usage trade-off between links and servers as a combined cost minimization problem, which is an integer programming problem. Private (used by one single flow) middleboxes can save more link bandwidth resources while shared (used by multiple flows) middleboxes cut down server resource expenses. After proving the NP-hardness of our problem in a general topology, we propose a performance-guaranteed algorithm to solve the single middlebox deployment problem with an approximation ratio of 2 for binary trees and k for k-nary trees. We also propose a strategy based on a self-defined submodular function with a better approximation ratio. Then, we extend our setting to deploy a service chain and introduce an efficient algorithm, which has an approximation ratio in a particular situation. Extensive simulations are conducted to evaluate the performance of our proposed algorithms in various scenarios.
pp. 643-651