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Networking Research for the Arab World: From Regional Initiatives to Potential Global Impact

THE ARAB REGION, composed of 22 countries spanning Asia and Africa, opens ample room for communications and networking innovations and services and contributes to the critical mass of the global networking innovation. While the Arab world is considered an emerging market for communications and networking services, the rate of adoption is outpacing the global average. In fact, as of 2019, the mobile Internet penetration stands at 67.2% in the Arab world, as opposed to a global average of 56.5%.¹² Furthermore, multiple countries in the region are either building

new infrastructure or developing existing infrastructure at an unprecedented pace. Examples include, Neom city in Saudi Arabia, the new administrative capital in Egypt, as well as the Smart Dubai 2021 project in the United Arab Emirates (UAE), among others. This provides a unique opportunity to fuse multiple advanced networking technologies as an integral part of the infrastructure design phase and not just as an afterthought.

Among a number of emerging communications and networking technologies, wireless and mobile technologies are of paramount importance and have become a key enabler for a multitude of services in our daily lives. Nowadays, mobile broadband technologies offer ubiquitous access to novel services and Internet access to billions of people around the world. The Arab world is no exception, considering the research work done in the region for advancing wireless systems and deployments. Over the course of each decade starting 1980, the world has witnessed four generations of cellular networks, each introducing a specific set of technologies and a portfolio of supported new use cases. As a 4G standard, Long Term Evolution (LTE) has become the most successful mobile wireless broadband technology, serving billions of users while handling a wide range of applications. Despite some disparity in regional availability of LTE/4G, the telecommunications industry has already started rolling out the fifth generation (5G) of mobile communications since late 2018, bringing a significantly wider range of new use cases and unprecedented capabilities. Example 5G technologies that enable this vision include, but are not limited to, pervasive artificial intelligence, beyond THz-band communications, intelligent reconfigurable surfaces, and Internet of Space Things (IoST), among others. The latter is instrumental in extending seamless connectivity and mobile services to rural, subma-

rine, and hard-to-reach areas, through an integrated system of CubeSats, tethered balloons, and unmanned aerial vehicles (UAVs). To match those needs, networks have evolved in numerous ways, including the growing role of artificial intelligence and machine learning (AI/ML) in designing and optimizing networks and extensions to airborne and underwater networking infrastructure, as will be presented in this article. In addition to technology breakthroughs, novel rollout roadmap, market readiness, education, and research opportunities also emerge all over the globe.¹

There is a tremendous amount of effort going into networking research at Arab academic and research institutions. Those efforts are not only motivated by the unique needs of the Arab world but also have a potential for global impact due to the similarity of networking research challenges in

different parts of the world. In light of this promising trend and technological progress of networking in the Arab world, we unveil in this article a sample of relevant research activities. We have organized the article into five themes that symbolize collaborative efforts across the Arab world for solving challenging and intriguing networking research problems that are key to the region's sustainable economic development and prosperity.

Machine Learning and Edge Computing in the Newly Developed Arab Smart Cities

In today's complex communication systems, not only is the parameter space large, but it is also time varying, and more often than not, involves objective functions that are highly non-linear and/or of polynomial/exponential complexity. ML offers a solution for setting and continuously updating

key network parameters based on actual usage patterns. ML models that can learn from prior experience/data using automatic feature extraction to alleviate the need for tedious manual extraction.

In a project jointly initiated by King Abdullah University of Science and Technology (KAUST) and the American University in Beirut (AUB), the researchers plan to review how AI/ML can be used for a variety of wireless design problems, including channel modeling and estimation, channel encoding and detection, power control and beamforming, and network optimization and resource allocation.⁹ In addition, opportunities and challenges are explored when integrating AI/ML approaches with new infrastructure deployment which lacks historical usage patterns and, hence, implies alternative approaches such as transfer learning and online training

and inference. The systems mentioned in this article have a great potential for planning reliable wireless systems for future Arab smart cities. These smart cities are special of its kind as they have the advantages of being planned and constructed on a new landscape, integrate the latest-edge technologies, consider the environmental effects, and operate on clean energy.

On a related front in Egypt, an ongoing research project funded by the Information Technology Industry Development Agency (ITIDA) and led by ElBatt at the American University in Cairo (AUC), in collaboration with the industrial partner IoTBlue,^a focuses on leveraging edge computing, jointly with cloud computing, towards distributed machine learning and scalable Internet of Things (IoT). The project involves the research, design and development of a prototype for a multi-tier computing system, spanning the edge, gateway and cloud tiers, with small-scale, short-term learning carried out at the two edge tiers while large-scale, long-term analytics at the cloud. The major contribution of this work is twofold: a novel machine learning model; distributed across devices in a single tier and across multiple tiers and, achieving minimal communications overhead while attaining similar or close prediction accuracy to the centralized ML baseline. It gives rise to a multitude of interesting research problems ranging from architecting the multi-tier computing system, distributed machine learning, intra-edge tier and across tiers, hosting heterogeneous sensors and IoT platforms, wireless networking and edge computing. The proposed system finds wide application in diverse IoT verticals like health, intelligent transportation and smart cities, being highly relevant to the new administrative capital, currently under development, as well as Cairo which is considered the most populous city in the Arab world and Africa and the sixth populous city in the world.

Finally, a relevant research thrust at Carnegie Mellon University in Qatar

lead by Harras targets intelligent resource allocation for the mobile cloud, in particular FemtoCloud and edge computing. FemtoCloud has a vital rule in facilitating ultra-reliable and low-latency traffic and decision making for sensitive smart-city applications. For instance, RAMOS⁵ is a resource-aware multi-objective system for edge computing. The system prototype achieves up to 40% completion time improvement under latency minimization mode and up to 30% more energy-efficiency under the energy-efficient mode. The team also developed computational offloading schemes that maximize the lifetime of the ensemble of mobile devices where they consider a mobile network while no device has depleted its battery. They also demonstrated the effectiveness of the computation offloading system that contributed to extending the lifetime of a mobile device cloud.

Flying UAVs for Smart Management in the Arab Cities

Flying networks are envisioned to play a vital role in city and disaster management through disaster prediction, response, recovery, as well as mitigation. They are also considered as one of the most promising technologies for disaster management according to recent Red Cross and UN reports.¹⁴ They present themselves as aerial base stations equipped with intrinsic communications, computing, and sensing capabilities. In particular, unmanned aerial vehicles (UAVs) have attracted strong interest from, both, research and industry communities owing to their agility, flexibility, and low cost. In terms of communications and connectivity, UAVs are deployed to provide immediate network infrastructure recovery for potential survivors and first responders, yielding timely emergency response.

A research project carried out by the Lebanese American University (LAU) deploys a swarm of UAVs that are autonomously distributed in 3D space to provide the needed network coverage over a given disaster scene and adapts its location dynamically to accommodate user mobility using low-complexity, real-time algorithms. This research is extended to develop a novel approach that allows rescue

teams locate victims based on the received signal strength indicator from their mobile devices. The proposed localization approach caters to disaster scenes with heterogeneous structure, allowing areas with a higher degree of damage or population density to be better served with a finer level of accuracy. To do so, UAVs sniff wireless signals from the victims' mobile devices to accurately determine their locations using optimized trajectories while accounting for channel variability. Low complexity algorithms have been developed and validated using an experimental testbed under realistic conditions to demonstrate the feasibility and effectiveness of UAV-based flying networks during emergency relief and rescue operations. Moreover, the UAV can be augmented with a reinforcement learning agent to search for victims and continuously improve the localization precision as long as the UAV's energy is not drained.

On another front in the UAE, the center for autonomous and robotic systems at Khalifa University, along with the internationally recognized MBZIRC robotic challenge partners¹³ are focusing on next generation intelligent robotics. This includes low altitude visual tracking UAVs that utilize deep learning. They run several projects for smart city management using UAV autonomous swarms and environmental imagery.¹⁰ As Dubai announced the Smart Dubai initiative, local research institutions devoted much efforts toward utilizing UAVs to cater to this ambitious initiative. Dubai have deployed UAVs for Geospatial and surveying activities. They also deployed it for civil security control, traffic management, agriculture projects and environmental management.

Underwater Internet Using Wireless Optical Networks for Red Sea Coral Reef Monitoring

Underwater wireless communications play an important role in environmental monitoring, underwater exploration, and scientific data collection. In this arena, KAUST is leading multiple research projects relevant to coral reef monitoring in the Red Sea. This environmental and marine life regional

^a IoTBlue (<http://www.iotblue.net>) is actively participating in a number of projects related to automation and smart cities in Egypt and the region.

need is motivated by evidence that coral reefs are facing growing challenges which call for extensive multi-disciplinary research to better understand the phenomena and address it. State-of-the-art submarine exploration missions typically demand efficient, flexible, and high data rate communications to access biological data collected by divers and unmanned vehicles.

Conventional radio frequency (RF) and acoustic communications critically suffer from severe attenuation of RF signals in water and low data rates (100bps to 100kbps), for acoustic waves, due to the low propagation speed (1500m/s) and large latency. On the other hand, underwater optical communications, based on diffuse (LED) and collimated (Laser) light sources, has been explored as a promising solution to support much higher data rates over ranges up to several tens of meters, thanks to their cost-effectiveness and low power consumption. In light of this, the research project of Underwater Internet Using Wireless Optical Networks led by Alouini, Ooi, and Shihada provides high data rate, low-power underwater communications that can overcome the aforementioned channel impairments and has practical relevance.

This project successfully characterized the statistics of fading for underwater optical wireless communication (UOWC) channels and analyzed the system performance. Furthermore, it developed a novel high-speed gallium nitride (GaN)-based laser diode that has a set of unique traits tailored for the Red Sea. Also, the project developed a low-cost, energy-efficient transceiver for UOWC systems supporting high data rates (up to 1Gbps over ranges up to 120 meters). Finally, the team built a prototype and performed system testing and debugging to ensure smooth, reliable live video streaming using underwater laser diodes. The research team has further extended the system to the experimental stage with a breakthrough demo, for the first time, of a bi-directional UOWC system capable of transmitting an ultra-high-definition (UHD) quality, real-time video over 4.5m. Following this break-

through, a low-power and compact UOWC system, coined Aqua-Fi,¹¹ has been proposed and deployed by the same research team. Aqua-Fi is an underwater wireless Internet solution hosting an Internet bridge, a transmission modulator onto an optical carrier, a transmitter equipped with projection optics and beam steering elements, a detector, and a signal processing unit. Aqua-Fi is a cost-effective solution using low power, off-the-shelf components (for example, LEDs and lasers) to achieve at least 1Mbps underwater data rates.

The successful implementation of Aqua-Fi could significantly advance work in coral reef ecosystems, in general, by facilitating the real-time transfer of continuous data streams. Numerous applications, such as live feeds from monitoring equipment and other sensors, could provide management entities with dynamic information critical to their decisions. Also, Aqua-Fi facilitates communications and data sharing among divers, bringing marine science into the 21st century. Aqua-Fi has brought the attention of both the research and the industrial communities. For example, as of July 19, 2020, Yahoo (71.4 million read), TechCrunch (12.4 million), and Hindu (13.5 million). There are also several published video interviews, podcasts, and many others.^b

5G Research and Deployment Initiatives in North Africa

Over the past three decades, wireless technologies have experienced exponential growth, fueled by breakthroughs in semiconductors, thanks to Moore's Law, and information and communications theory. Apart from the currently launched 5G communication systems, beyond 5G (B5G) systems promise to reinvent entire industry sectors, by creating new use cases and models such as massive IoT connectivity, augmented reality, virtual reality (AR/VR), Vehicular-to-Anything (V2X), among others. These new use cases demand network support with large degrees of freedom. Furthermore, the vision for the sixth

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^b Aqua-Fi Project <https://www.shihada.com/node/141>, and <https://github.com/CBinda-house/AquaFi>

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generation (6G) wireless networks is based on various breakthrough technologies expected to realize global connectivity across vertical industries with a plethora of innovative applications and services.⁴

Multiple research groups in Egypt are actively working on various aspects of 5G communications and networking research ranging from the network infrastructure to new application scenarios and emerging services. Those efforts include novel wireless technologies, mobile and edge computing and wireless test-beds for education and research. The importance of wireless and mobile networking technologies, in general, and 5G technologies to Egypt and the Arab world stems from: the ease of deployment, maintenance and upgrade in dense population cities, like Cairo and providing reliable Internet connectivity to remote, underserved areas, especially for remote health monitoring, learning and working, for example, at the time of COVID-19 lockdown. Among the prominent networking research activities in Egypt are, most notably, the ongoing work and collaboration of research groups at Cairo University, Alexandria University and Egypt Japan University of Science and Technology (E-JUST), The American University in Cairo (AUC) and the Wireless Intelligent Networks Center (WINC), Nile University. A significant body of research has been developed over the past few years on 5G networks, with publications in high-impact journals,^{2,4,6} through collaborative projects among researchers at the Cairo University, AUC and Nile University, in addition to Qatar University and Sabanci University, Turkey. First, the design and optimization of energy-efficient wireless networks and energy harvesting 5G networks toward reducing the carbon footprint in dense Arab cities, like Cairo. This among other networking research efforts hinge on the abundance of renewable energy sources in most Arab countries, for example, solar, wind, and RF interference.² Second, optimization of cognitive radio networks toward efficient spectrum utilization, which is a global research challenge with an

impact that goes far beyond the Arab world.

Caching at the wireless network edge,⁶ with potential applications in wide-scale content distribution to reduce the volume of download traffic at rush hours, for example, remote learning settings more common nowadays. Another research thrust at Cairo University has focused on 4G/5G interference management catering to dense population cities, for example, metropolitan areas.⁷

Finally, heading west in North Africa, namely to the “Maghreb” region (the western end of the Arab world), researchers with Hassan II University of Casablanca in Morocco and University of Carthage in Tunisia propose to introduce a set of best practices of 5G networks, in terms of deployment and spectrum management. Among multiple 5G configurations, two deployment models have been standardized to match market requirements and need to be expatiated on. The first deployment approach is Non-Standalone (NSA) where the 5G New Radio (NR) is connected to, and controlled by, the existing 4G core network and only supports Enhanced Mobile Broadband services. On the other hand, the Standalone (SA) approach fully exploits the capabilities of the 5G NR and the 5G core and allows to support Massive Machine Type Communications and ultra-reliable and low latency communication (URLLC) services.

Morocco was expecting to launch its first 5G network in late 2020. However, due to the COVID-19 outbreak, the 5G rollout has been postponed to 2021 or early 2022. In early 2019, Maroc Telecom (IAM) had teamed up with Ericsson to showcase a live 5G demonstration at IAM's headquarters in Rabat. This pilot staged several 5G use-cases demonstrating very high speeds reaching up to 25.8 Gbps. Indeed, Orange Morocco and Huawei have performed several 5G trials in March 2019. INWI is the first Moroccan operator to have signed an agreement with Huawei. Since mid-2019, they succeeded in deploying many pre-commercial 5G pilot projects supporting numerous 5G use-cases. For a smooth rollout, policymakers should reduce the

regulatory costs and fees, and provide affordable 5G handsets.

Based on the collaborative research effort across Morocco and Tunisia, it is observed that the Maghreb region has a strongly emerging 5G community aiming to facilitate the worldwide harmonization of research and best practices for the deployment of viable user scenarios within the global 5G ecosystem, built-in security and privacy by design in 5G, and explore the different approaches to reach efficient IP convergence.

Limited Resources and Remote Learning Support During COVID-19

Traditionally, networking protocols are validated using simulations, emulation, or testbeds. Simulations can provide large-scale evaluation but may not reflect reality. Emulation and implementation of real testbeds may be limited to the available resources. An interesting project at the Wireless Research and the Smart Critical Infrastructure centers at Alexandria University, Egypt is the WiPi Project.³ WiPi aims at providing a low-cost remotely accessible wireless networking testbed, a requirement for realistically validating networking protocols. It allows researchers and practitioners to run large-scale wireless experiments remotely. The testbed is realized using low-cost Raspberry Pi nodes as the computing resources and employs concepts such as resource pooling, node virtualization, and federation to maximize resource utilization and reduce the overall testbed cost. This not only allows for larger testbeds but also helps reach a larger pool of users, especially in these days of COVID-19 where remotely accessing education and research facilities is a priority. The testbed started as a single testbed in Alexandria University and is now federated to include Cairo University, AUC, E-JUST, and Assiut University. Users may run their experiments across nodes in the different sites concurrently and the testbed smoothly handles distributing the experiment on the testbed nodes to achieve a variety of goals.

Several research efforts highlighted the increasing evidence of viral spread due to aerosol transmission, where small particles can be trans-

ferred through the aerosol channel for long-distance causing infection. Recently, a research initiative from KAUST led by Alouini and Shihada have proposed a novel research direction called “Communication via Breath,” which visualizes the viral spread mechanism as a piece of transmitted information through a molecular communication channel.⁸ The proposed “Communication via Breath” concept utilizes the breath as a source of messages, where several bio-information can be transmitted through molecular aerosol channel. The information is carried by several biological entities such as pathogens and VOCs, which also act as health biomarkers. Bringing such a biological problem under the molecular communication umbrella enables researchers to apply mathematical methodologies, approaches, and analysis tools from information and communication technology research to model, analyze, study and deal with the problem of viral aerosol spread. Interestingly, the new visionary research attracted molecular communication researchers to conduct research that can support our concept. Notably, some algorithms are developed to estimate the transmission distance, and some model is proposed based on fluid dynamics. Indeed, the novel “Communication via Breath” research is related to the progress in three areas, information and communication technology, fluid dynamics, and molecular biology.⁸

Conclusion

In this article, we presented prominent networking research activities under five major research themes highly relevant to the Arab world. The prime objective of this article is to draw the attention of the international networking community and raise awareness about the imperative contributions of world-class research coming out of this part of the world. In addition, we highlight the key role networking is playing as part of the Digital Transformation initiatives taking place around the Arab world. Based on the outlined research efforts with regional focus yet hosting challenges common to other parts of the world, we envision ample room for a

potential global impact via leveraging key insights, enabling technologies, lessons learned and major findings of this research in other parts of the world. This article should also open venues for intra- and inter-region collaboration opportunities in the vibrant area of networking and related verticals.

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