ERCIM "ALAIN BENSOUSSAN"
FELLOWSHIP PROGRAMME

Scientific Report

First name / Family name	Devendra Gurjar
Nationality	India
Name of the *Host Organisation*	NTNU Trondheim
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Period of the fellowship	01/09/2022 to 30/11/2022

I – SCIENTIFIC ACTIVITY DURING YOUR FELLOWSHIP

During the ERCIM fellowship, I worked in the Department of Information Security and Communication Technology at NTNU Trondheim, where my research mainly focused on two application areas, i.e., vehicular communications and unmanned aerial vehicle (UAV)-enabled communications. Accordingly, the following research activities were conducted.

A. Scientific activity on vehicular communications:

The first research activity focussed on enabling communications between vehicles to the network (V2N) with low latency and enhanced communication reliability. In general, vehicular communication has been introduced to realize the implementation of automatic vehicle systems, intelligent traffic handling, and improving the safety of drivers, passengers, and pedestrians. It aims to modernize vehicle operation, help drivers make appropriate decisions, manage vehicle traffic, and offer practical applications for passengers. With the advancements in wireless technological standards, intelligent transportation systems (ITS) are a potential solution to real-time on-road problems, such as handling traffic congestion, traffic mishaps and ensuring the safety of drivers, passengers, and pedestrians. With onboard communication modules, automated

vehicular networks have come to reality, but there is still a need for a more generalized large-scale networked vehicular society.

Moreover, the vehicles can also interact with the infrastructure, such as roadside communication terminals or base stations, based on the cellular systems for route mapping and localization. The primary objective of this work was to implement a robust and reliable network to enable communication for vehicles located at a farther distance apart. The proposed system connects vehicles to the network (base station) using the roadside infrastructure in two phases. In order to enhance the reliability and data rates, a mixed RF and hybrid RF/ free-space optics (FSO) network can be the optimal solution for V2N communication where an RF link is utilized in the first phase and hybrid FSO/RF links for the next phase for information transfer from vehicle to the network. Using an FSO link ensures higher data rates, lower latency, lower interference, and ease of deployment and scalability. As the FSO link can be affected due to atmospheric turbulence, it can be aided by the RF link, thus increasing the system's reliability. The significant contributions of this work can be summarized as follows:

- We considered mixed RF and hybrid FSO/RF transmissions for V2N communication by taking into account all the factors that can affect FSO performance, i.e., atmospheric turbulence-induced fading, misalignment errors, and atmospheric attenuation.
- By considering the mobility of the vehicle in modeling the V2I link, the time selective fading nature of the V2I link was characterized using a first order auto-regression process. The effect of the relative speed of the vehicle and the vehicle transmit power on the considered performance metrics were assessed.
- We proficiently derived the closed-form expressions for the outage probability, average symbol error rate, and average end-to-end delay of the system by considering all the intricacies involved in obtaining the expressions for the multi-hop network.
- We disclosed the impacts of various system design and channel parameters on the considered performance metrics of the system. Specifically, the effect of pointing errors and atmospheric turbulence-induced fading on the average end-to-end delay performance of the system was studied. Also, the impact of FSO link distance and length of the transmitted packet on delay performance was investigated.

B. Scientific activity on UAV-enabled communications:

In the second research activity, we explored the concept of radio frequency (RF) energy harvesting techniques in the UAV-enabled terrestrial communications, including vehicular systems. Specifically, it includes the scenarios where UAVs suffer from onboard power limitations, affecting their flight duration and maneuverability. To overcome the UAV's power constraints, different RF energy harvesting techniques can be employed in order to facilitate wireless information and power transmissions. Alternatively, UAVs can also be exploited to enable seamless connectivity between energy-constrained low power Internet of Things (IoT) devices in remote locations, disaster-struck areas, emergency situations, and areas where human intervention is challenging and recharging or replacing their batteries is not possible. These devices often have very low transmit power and may not be able to communicate over a long range. Therefore, a low-altitude UAV can fly

flexibly and serve as an energy transmitter to charge the nearby low-power devices efficiently. UAVs and energy harvesting techniques are two promising future generations paradigms to enable ubiquitous connectivity. Here the former exploits its strong line-of-sight (LoS) link and deployment flexibility, whereas the latter utilizes ambient and dedicated energy sources to harvest the energy for extending the network lifetime. Motivated by this, we initiated conducting a comprehensive literature survey on the current state of RF assisted UAV communication with upcoming wireless techniques.

II – PUBLICATION(S) DURING YOUR FELLOWSHIP

[1] V. Sandeep, D. S. Gurjar, S. Yadav, P. Pattanayak, and Y. Jiang, "On the performance analysis of V2N mixed RF and hybrid FSO/RF communication system," *IEEE Photonics Journal*, accepted for publication, November 2022.
Online Available: https://ieeexplore.ieee.org/document/9961849

[2] G. K. Pandey, D. S. Gurjar, Y. Jiang, and S. Yadav, "Wireless power transfer in UAV-enabled communications: A comprehensive survey," under preparation.

III – ATTENDED SEMINARS, WORKHOPS, CONFERENCES

I have virtually attended an international conference, "2022 IEEE Silchar Subsection Conference (IEEE SILCON-2022)", held during 4-6 November 2022, India.

IV – RESEARCH EXCHANGE PROGRAMME (REP)

I have not visited any other ERCIM institute.