**Novel Transmission Techniques for Visible-Light Communications**

**Résumé du projet de recherche (Langue 1)**

Motivation The birth of 5G networks will be characterized by a thousandfold increase in mobile traffic volume per square meter and involve the harmonization of a patchwork of techniques providing both increased spectrum-efficiency and increased spectrum utilization. Among those for increasing spectral-efficiency we can highlight continued use of multi-port transmission (MIMO, multiuser MIMO, distributed MIMO / cooperative-multipoint, etc) and both multi-point signal-level interference-mitigation techniques as well as interference-limiting coordination at the network-layer between infrastructure elements (basestations and relay nodes). Increased spectrum-utilization will firstly rely on dynamic radio-spectrum access in unused licensed or unlicensed bands or geographically-dependent unused bands (e.g. TV White Spaces). Secondly, and arguably more importantly, the migration to millimeter-wave frequencies should allow for efficient exploitation of massive amounts of available spectrum[reference]. Although bandwidth is plentiful in millimeter-wave bands, communication is restricted to small areas and mainly line-of-sight links especially due to power-limitations in mobile terminals. This requires a densification of the radio network which will be seen in the form of an explosion in the deployment of small-cells with an efficient, high-throughput and low-latency optical backhaul [reference]. Free-space Optical Channels In addition to such millimeter-wave small-cells, the use of free-space optical channels has been proposed for high-bandwidth wireless data communications, especially in the form of visible-light communications (VLC). VLC approaches using conventional LED lighting equipment that can be bought in hardware stores used in conjunction with relatively low-cost and tiny photo-sensors have been shown to be feasible for transporting high-bandwidth spectrally-efficient OFDM waveforms [reference], currently up to 1.6 Gbit/s with a single-colour LED. One of the interesting consequences of using VLC is that the deployment of communications infrastructure is coupled with lighting, and, moreover, good lighting coverage will ensure good communication links. This could even be true in the case of non-line-of-sight scenarios since modern indoor environments are conceived with materials that guarantee good lighting conditions even with reflections. Exploitation of this symbiosis will be extremely beneficial in locations such as airports, shopping centers, office buildings, super-markets, etc., which are all examples of locations where high-throughput wireless communications are expected with even today’s smartphones. Another clear benefit of the symbiosis is energy consumption, in the sense that the communications component does not require additional power for transmission since it exploits the high-power transmission used for lighting. Advanced Multiport Transmission Similarly to radio-based systems, multi-port transmission (i.e. MIMO and/or adaptive beamforming) is feasible with LED lamps, which are usually an aggregation of many low-power emitters. An example of using massive multiport transmission (massive MIMO) with VLC is [NI/Cambridge] and should be considered as a candidate technology in the 5G patchwork. Innovative multiport processing for LED-based transmission is still in its infancy. In particular, the benefits of MIMO transmission, whether point-to-point or multiuser-MIMO, are yet to be determined. This is primarily due to insufficient understanding of the propagation characteristics of free-space optical links. Coordinated multipoint transmission (CoMP) may be simpler with VLC transmitters because of the number of lighting sources that are available in typical indoor environments. Finally, through CoMP, VLC transmission could provide very accurate positioning possibilities. This is due to the fact that multiple optical channels with significant carrier-spacing (orders of GHz) can be used to allow terminals Standards Industry cooperates to promote the use of VLC through the so-called LiFi or light fidelity consortium. LiFi approaches the standardization of VLC waveforms and protocols through the now out-of-date IEEE 802.15.7 standard proposal. The pitfalls in this approach are firstly that the physical-layer waveform does not consider and is not particularly well-adapted to high-spectrally efficiency techniques (OFDM, MIMO, beam-forming etc.) and secondly that the proposed protocols are not conceived for tight (low-layer) heterogeneity with radio-systems. These are both extremely unfortunate with respect to the massive future usage of VLC technology. In the context of low-power terminals, like smartphones, VLC can make maximal impact if used for high-throughput downlink communications, either in the form of multicast/broadcast radio bearers or unicast bearers whose uplink counterpart (including necessary low-layer signaling for channel state information and channel decoding integrity) is transported using legacy radio services. It could be argued that a tight interaction between radio and optical components should be considered at the level of baseband processing as well. Since OFDM transmission (e.g. 4G waveforms) is feasible on a free-space optical link, it is definitely worth considering using the same basic waveform and protocol stack for radio and VLC components. This would allow for a common baseband processing platform in both the small-cell transmitters and terminal receivers. Moreover, the LTE Rel-10/11 access-layer protocols are perfectly adapted to the use of Downlink-only component carriers. The 40 MHz of so-called Supplemental Downlink Channels (1452-1492 MHz) will be used widely in Europe in conjunction with bi-directional carriers in the coming years.

**Résumé du projet de recherche (Langue 2)**
Detailed Objectives

Objective 1: Assessing the feasibility of transporting standard-compliant radio waveforms (4G/5G) using VLC. This objective aims to determine to what extent Rel-10+ LTE small-cells for large indoor environments can be augmented with visible-light (VLC) optical component carriers which are downlink-only. The feasibility study will address the use of the existing LTE access-stratum protocols for a hybrid radio and VLC small-cell. The VLC components will assume a combination of unicast and broadcast (eMBMS) bearers and we would use the LTE physical-layer, as is, on the optical link. A. Infrastructure components (electronics): From the perspective of the infrastructure elements, the study will determine the impact for small-cell solution providers, firstly in terms of the underlying electronics in the eNB, namely how to interface the VLC component with the baseband processor. Methods which require minimal changes in standard eNB architectures will be favoured. Architectural conclusions will provide input to the prototyping and validation activity. B. Infrastructure components (software): Secondly, the methods for allocating radio resources between radio and VLC components in an optimal fashion will be proposed and includes exploitation of advanced signal processing possibilities for VLC which will be addressed subsequently. This will provide insight into the dimensioning of VLC component carriers between broadcast/multicast and unicast operation. Impact on dynamic scheduling algorithms for hybrid radio/VLC operation will be considered. This component relies on analysis of scenarios where VLC will play an important role. It will provide important outputs to study items related to innovations in signal-processing for VLC. C. Terminals: From the perspective of user equipment (UE), the candidate will study integration issues for providing photo-sensors in smartphones in conjunction with the radio-modems. A key part of study is to assess the capacity for re-using as much as possible of the radio MODEM for the optical carriers. Integration of photo-sensors for VLC has already been demonstrated using add-on modules in the last couple of years at tradeshows around the globe, but, to the best of our knowledge, this did not make use of the LTE PHY and protocol stack for the VLC component. This constitutes an important innovation to demonstrate. D. As directions for 5G waveforms become more clear, analysis of the adequacy of new waveforms, network topologies and protocols for VLC interoperability will be assessed.

Objective 2: Innovations in VLC Transmission

The candidate will propose innovations in VLC transmission which make use of distributed signal-processing techniques now common in radio systems. This objective will rely on a measurement system proposed by either EURECOM or the CEA-LETI. Specifically the candidate will address: A. Co-located Multi-port transmission achieving firstly point-to-point and more importantly multuser spatial-multiplexing with a single LED array. Secondly, the potential for highly-selective adaptive beamforming techniques using feedback on the radio-link will be assessed. This actively will require propagation measurement campaigns for the VLC component. B. Distributed Multi-port transmission using multiple spatially distributed LED arrays. This activity will also require propagation measurement campaigns for the VLC component and will be used to show the potential benefits in terms of spatial-multiplexing and localization. For the second application at least two channels with sufficient frequency spacing will be required. State-of-the-art LED arrays with maximal switching bandwidth will be used.

Objective 3: Prototyping and Validation of Key Innovations

The candidate will make use of an existing validation platforms showing the feasibility of hybrid-use of 4G and VLC transmission. The validation platform showing Rel-10 carrier aggregation with hybrid radio and VLC transmission will be integrated again using www.openairinterface.org LTE prototyping equipment. Commercial Rel-10 UEs will be used. In order to show the salient features of hybrid transmission, advanced transmission techniques will not be considered as in Objective 2 which is limited to off-line exploitation of measurement results. At least one bi-directional primary component carrier (radio) will be considered in conjunction with at least one downlink-only VLC component carrier. Dissemination The thesis will aim to produce significant scientific results in top IEEE conferences such as IEEE ICC and Globecom or ACM Mobicom as well journals such as IEEE Transactions on Wireless Communications.