Self-organizing flying mobile relays for wireless Internet access networks

Mots clés :
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- Domaine scientifique principal : Divers

Résumé du projet de recherche (Langue 1)
This PhD project proposes to study the use of flying mobile relays as a way to improve coverage, capacity, and flexibility in future mobile internet access networks. (Self-)controllable drones that carry wireless transceiver equipment in order to relay information streams between the infrastructure and user terminals, as well as other type of communication, storage and processing devices, yield the promise of ultra-flexible network deployments, able to provide coverage and capacity when and where it matters the most. Studies of the benefits of such flying relays in mobile networks (5G and beyond) have recently started to arise in the literature [JYM2014, MSB2015, IEY2016, CG2016,]. In the civilian networking area, initiatives include those by prominent Internet content providers Google and initial ones from Facebook where the exploitation of some large aerial platforms (usually from a fairly high altitude) to help relay internet access possibly from satellite backhaul towards rural or developing areas, has been featured recently in popular media. In October 2016, another effort to leverage UAVs in the context of small cells for urban deployment of 5G and Beyond was announced by Nokia where this time regular-sized drones were used as delivery tool (reminiscent of Amazon's initiative with parcels) to carry and drop small cell base stations at suitable locations in the network where they are most needed. In this project we will consider the use of smaller, low altitude UAVs which offer a much better position control and can form radio beams to spatially discriminate between close-by groups of user terminals on the ground. We will focus in particular on the problem of optimum (autonomous) positioning of such flying relays, in individual or fleet form. Optimized Deployment of one mobile flying relay in order to capitalize on the flexibility and fast adaptation capability of aerial networks, the UAV must be enabled with a smart positioning algorithm that solves a challenging multi-purpose optimization. This optimization is a challenging problem which will be addressed at the heart of the PhD thesis. In particular drones must autonomously design a trajectory that simultaneously maintains (i) a good connection to the wireless hubs (i.e. a variable that relates the altitude of the drone-cell to the radius of its coverage area to the ground user). In doing so, the self-positioning algorithms must intelligently exploit local propagation measurements (for instance to maximize line of sight connections or the Signal to Noise Ratio – SNR). minimize interference to/from non-served users, and finally smoothly adapt to spatio-temporal patterns of ground traffic demand. Finally, in the scenario of UAV fleet deployment, the UAVs should coordinate between themselves to optimally divide the coverage task among themselves, as addressed in the next section. The problem of optimizing the position of a single flying relay [t45 was addressed in some recent work based on a combination of air-to-ground (ATG) channel modeling and subsequent numerical analysis of the relay channel capacity via the UAV. When it comes to ATG channel modeling, a fine representation of the path loss and the likelihood to meet line of sight was found critical. Some early works on ATG channel analyzed this LoS probability via statistical analysis and some models were derived [FTN2006a], subsequently a propagation model valid for frequency ranges from 200 MHz to 5 GHz is obtained via combining of LoS probabilities, the accounting of random shadowing and ray tracing techniques [FTN2006b]. The model also accounts for the height and elevation angle of the UAV seen from the ground user. Other ATG models are designed for standardized simulations such as the one characterized by the ITU-R Rec. P.1410; for instance, [AKJ2014] describes a generic radio model between a low altitude platform and ground nodes using frequencies from 700 MHz to 5.8 GHz based on random virtual city maps and ray tracing. In the current literature, channel models are exploited to obtain UAV positioning and trajectories based on numerical optimization. An example is [LOC2016], which considers multiple UAVs with the aim to maintain the overall network connectivity in a 3D scenario with several ground nodes. The optimal position of drones acting as relays is found through the particle swarm optimization, following different network performance metrics. In [MSB2015], the optimal three-dimensions placement of multiple UAVs was addressed to optimize downlink coverage in terms of antenna gain and UAVs altitude. Dist packing theory was used to handle the interference of the overlapping coverage areas of the UAVs, while minimizing the transmit power. The novelty introduced by [IEY2016] is summed up by creating a variable that relates the altitude of the drone-cell to the radius of its coverage area to the ground user. The authors investigated the air-to-ground channel and how it differs from those of terrestrial channels of macro base stations. Their results were based on mixed integer non-linear optimization technique. Other numerical optimization based methods for UAV location optimization can be found in [SSR2016],[JYM2014],[JZC2012],[MSB2015],[HSL2014]. When it comes to UAV positioning, this project will depart from previous studies in several ways. First we take a deliberate “data science” approach which will allow to exploit real life measured data (SNR, signal strength) directly into position modeling, and reduce the dependency on a possibly too descriptive propagation channel model. Learning algorithms will then be investigated to reconstruct global radio maps from the initial measurements and models, in a way similar to some of our preliminary work [JYG2016][JG2016] which introduces some machine learning tools for radio map reconstruction from sparse UAV-based measurement and subsequent positioning. Secondly, the learning algorithms will be designed in a way similar to positioning also accounts for spatio-temporal patterns of ground user data demands. The demand patterns can be estimated from histograms based on user data request logs. This will help UAV position itself not just where propagation conditions are most favorable but simultaneously where its presence is most relevant from a global traffic point of view. Importantly, we will consider important categories of implementation scenarios, namely the off line and on line algorithms. In the off line scenario, the algorithm is run in a central computing node belonging to the infrastructure, based on collected channel and traffic measurements. In the on line case, there is no need to pre collect all the measurement information, instead the flying relay is gathering information on-the-go and adjusts its position in real time to account for such instantaneous measurements. We will study the performance gap between the two solution and attempts to derive innovative on line solutions which minimize the gap. Coordination of a fleet of UAVs Finally, as our scenarios also consider the possibility of deploying a fleet of UAVs to meet with coverage constraints in large populated areas, coordination mechanisms allowing the UAV to self-organize and divide the coverage tasks among themselves will be considered. Because such coordination methods cannot rely on a reliable backhaul of inter-UAV communications, the algorithms will be made decentralized and robust to uncertainties in channel state and position information. We will build on the mathematical framework of team decision theory to develop innovative and robust solutions in this area, see for instance the framework developed in [GK2016]. Experimental validation using the OAI platform In parallel with the above theoretical and algorithmic studies, the PhD candidate will be invited to test ideas within a real life experimental testbed provided by EURECOM. The testbed will capitalize on the existence of open source LTE software at EURECOM (OpenAirInterface) in order to demonstrate end to end cellular communication over-the-air on a base station to ground user link via the flying relay.

Résumé du projet de recherche (Langue 2)
Other ATG models are defined for standardized simulations such as the one characterized by the ITU-R Rec. P.1410; for instance, [AKJ2014] describes a generic radio model between a low altitude platform and ground nodes using frequencies from 700 MHz to 5.8 GHz based on random virtual city maps and ray tracing. In the current literature, channel models are exploited to obtain UAV positioning and trajectories based on numerical optimization. An example is [LOC2016], which considers multiple UAVs with the aim to maintain the overall network connectivity in a 3D scenario with several ground nodes. The optimal position of drones acting as relays is found through the particle swarm optimization, following different network performance metrics. In [MSB2015], the optimal three-dimensions placement of multiple UAVs was addressed to optimize downlink coverage in terms of antenna gain and UAVs altitude. Disk packing theory was used to handle the interference of the overlapping coverage areas of the UAVs, while minimizing the transmit power. The novelty introduced by [IEY2016] is summed up by creating a variable that relates the altitude of the drone-cell to the radius of its coverage area. The authors investigated the air-to-ground channel and how it differs from those of terrestrial channels of macro base stations. Their results were based on mixed integer non-linear optimization technique. Other numerical optimization based methods for UAV location optimization can be found in [SSR2016][JYM2014][JZC2012][MSB2015][HSL2014]. When it comes to UAV positioning, this project will depart from previous studies in several ways. First, we take a deliberate “data science” approach which will allow to exploit real life measured data (SNR, signal strength) directly into position modeling, and reduce the dependency on a possibly too descriptive propagation channel model. Learning algorithms will then be investigated to reconstruct global radio maps from the initial measurements and models, in a way similar to some of our preliminary work [JYG2016][JG2016] which introduces some machine learning tools for radio map reconstruction from sparse UAV-based measurement and subsequent positioning. Secondly, the learning algorithms will be design so that positioning also accounts for spatio-temporal patterns of ground user data demands. The demand patterns can be estimated from histograms based on user data request logs. This will help UAV position itself not just where propagation conditions are most favorable but simultaneously where its presence is most relevant from a global traffic point of view. Importantly, we will consider important categories of implementation scenarios, namely the off line and on line algorithms. In the off line scenario, the algorithm is run in a central computing node belonging to the infrastructure, based on collected channel and traffic measurements. In the on line case, there is no need to pre collect all the measurement information, instead the flying relay is gathering information on-the-go and adjusts its position in real time to account for such instantaneous measurements. We will study the performance gap between the two solution and attempts to derive innovative on line solutions which minimize the gap. Coordination of a fleet of UAVs Finally, as our scenarios also consider the possibility of deploying a fleet of UAVs to meet with coverage constraints in large populated areas, coordination mechanisms allowing the UAV to self-organize and divide the coverage tasks among themselves will be considered. Because such coordination methods cannot rely on a reliable backhaul of inter-UAV communications, the algorithms will be made decentralized and robust to uncertainties in channel state and position information. We will build on the mathematical framework of team decision theory to develop innovative and robust solutions in this area, see for instance the framework developed in [GK2016]. Experimental validation using the OAI platform In parallel with the above theoretical and algorithmic studies, the PhD candidate will be invited to test ideas within a real life experimental testbed provided by EURECOM. The testbed will capitalize on the existence of open source LTE software at EURECOM (OpenAirInterface) in order to demonstrate end to end cellular communication over-the-air on a base station to ground user link via the flying relay.