5G Flying Ad Hoc Networks

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Flying ad hoc network (FANET) is an application of 5G access network, which consists of unmanned aerial vehicles or flying nodes with scarce resources and high mobility rates. It is one of the new applications supported by 5G. 5G incorporates new technologies, including massive multiple-input and multiple-output (MIMO), device-to-device (D2D) communication, coordinated multi-point (CoMP), and beamforming, providing new features, such as exploring and exploiting mmWave and underutilized spectrum.

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1. Introduction

During the past decade, the internet has revolutionized almost all fields and has boosted the tremendous growth of user equipment (UE) and bandwidth-starving applications. By end of 2021, data traffic is expected to increase by eight-fold [1] with the introduction of next-generation bandwidth-starving applications (for example, augmented reality, virtual reality, and driver-less vehicle), and new services (for example, smart home, smart healthcare, and smart city).

Therefore, there is a colossal demand for significantly higher network capacity and lower delay to support higher mobility of UEs, leading to the need of the next-generation mobile wireless network, namely, fifth generation (5G). Flying ad hoc network (FANET) is one of the new applications supported by 5G.

5G incorporates new technologies, including massive multiple-input and multiple-output (MIMO), device-to-device (D2D) communication, coordinated multi-point (CoMP), and beamforming, providing new features, such as exploring and exploiting mmWave and underutilized spectrum. These features help to achieve improved spectral efficiency, coordinate different kinds of network cells (for example, macrocells and small cells (SCs), including picocells and femtocells) for achieving reduced interference, and achieve network virtualization for sharing network-wide resources. These features cater for next-generation network scenarios characterized by ultra-densification, heterogeneous, and high variability, in order to achieve a better quality of service (QoS) of up to 10× higher data rate, up to 1000× lower delay, up to 99.999% higher reliability and availability, up to 100× larger network coverage, and up to 10× longer battery lifetime [2]. As an example of the new technologies, D2D enables neighboring nodes to perform direct communication among themselves without passing through a base station (BS), which can offload traffic from the BS to reduce network congestion while reducing delay and energy consumption.

2. FANET

In FANETs, a large number of unmanned aerial vehicles (UAVs), which are autonomous, small-sized, and lightweight flying nodes, move at high speed at low or high altitudes in a three-dimensional space. Communication in FANETs is characterized by (a) a large transmission range due to the elevated look angle of UAVs, providing long-range connectivity with UAVs and base stations (BSs), and (b) frequent link disconnections and network partitions due to the high-speed and three-dimensional movement [3]. It was considered that all nodes in FANETs are UAVs with different characteristics and different roles, namely, cluster member (CM), cluster head (CH), cluster gateway (CG), and vertical cluster gateway (VCG). UAVs have become increasingly important to support resource starving applications of FANETs in 5G and beyond 5G mobile networks [4]. Examples of use cases are advanced mapping and aerial photography, in which UAVs must satisfy the ever-increasing demands for mobile data communication and ubiquitous connectivity to different kinds of wireless devices [4].

As UAVs are battery-powered with limited residual energy, frequent link disconnections and network partitions cannot be addressed by further increasing the transmission range, which can drain out residual energy. Consequently, network performance degrades, including higher overheads (for example, clustering and routing overheads, and handover) and lower quality of service (QoS) (for example, lower throughput and higher end-to-end delay). Therefore, efficient vertical routing is performed over a clustered network to increase network stability. One of the most critical issues of UAVs is how to consume the limited residual energy efficiently. The lifetime of the whole UAV network is highly dependent on the energy consumption of UAVs, which is related to their mobility patterns and data transmission. Although UAVs can be equipped with rechargeable batteries powered by solar energy, fuels, and other sources of energy, UAVs should not frequently return to ground stations to charge their batteries frequently, which can reduce their hovering time considerably. Therefore, efficient routing should be performed to enhance network lifetime [5]. In [6], the challenges of data transmission in FANETs, especially reducing its energy consumption, have been addressed. Nevertheless, the proposed approach focuses on increasing network lifetime, reducing energy consumption, and reducing the rate of link breakages for 5G or beyond.

In FANETs, multiple UAVs cooperate and establish an ad hoc network in a multi-UAV scenario. The presence of a large swarm of UAVs is called a multi-UAV swarm. Using 5G to support a multi-UAV swarm provides three main advantages: network scalability, network stability, and load distribution, for achieving improved QoS. As an example, device-to-device (D2D) communication allows neighboring UAVs to communicate with each other without passing through a BS, which can reduce control message exchange and enable traffic offload from the BS, leading to an increased bandwidth availability at BS [7]. As another example, small cells (SCs) are deployed to cater for local traffic in order to reduce energy consumption [8][9]. The BSs provide backhaul access, and they have the privilege to interact with central controllers (CCs). The CCs are responsible for (a) managing network-wide traffic and changes in network topology due to node mobility and dead nodes as a result of battery drainage, and (b) making intelligent routing decisions based on network-wide policies. Network-wide policies deal with vertical routing (for example, selecting the most favorable route across different network planes efficiently), whereas local policies deal with vertical clustering across different network planes.

3. 5G

5G is the next-generation wireless network that provides mobile internet connectivity with promising download and upload speeds, wider coverage, and higher stability. 5G incorporates various types of new technologies (for example, D2D communication), and coordinates different kinds of network cells (for example, macrocells and SCs, including picocells and femtocells) to reduce interference [10][11][12][13]. The network is generally segregated into different network planes comprised of different network cells; for instance, a macro-plane consists of macrocells. 5G caters for next-generation network scenarios characterized by ultra-densification whereby there is a large number of active UAVs per unit area generating a massive amount of data, and high heterogeneity whereby there is a diverse range of transmission capabilities among UAVs distributed in different network planes.

One of the key features of 5G is the presence of a CC and distributed controllers (DCs) to support the hybrid approach. The CC manages global information (for example, the residual energy of a UAV and the network plane in which a UAV resides), and allocates network-wide resources (for example, channels with spatial reuse). The DC manages local information (for example, the geographical location, node degree, and relative speed, of a UAV), and allocates local resources (for example, bandwidth and buffer space). This hybrid approach allows the CC and DCs to exchange the global and local information with each other. The presence of DCs allows control functions to be brought closer to UAVs and local infrastructure, particularly the BSs, leading to a reduced interaction time between UAVs and controllers, and increased throughput performance with higher bandwidth availability at the CC.

Using the new technologies of 5G, particularly D2D, across different kinds of network cells in FANETs reduces congestion level and increases throughput. D2D increases bandwidth availability at BS and can support the deployment of different network cells through spatial reuse of frequency bands.

4. Vertical Clustering

Vertical clustering segregates UAVs with similar nature or behavior into logical groups across different network cells in order to improve network scalability and cluster stability. While ultra-densification and large transmission range increase network connectivity among UAVs in a cluster, network connectivity among UAVs are affected by high heterogeneity and dynamicity. Traditionally, a cluster is comprised of cluster head (CH), cluster member (CM), and cluster gateway (CG). The CH, which serves as the cluster leader, manages and handles cluster-level operations (for example, routing), and performs intra- and inter-cluster communications. The CM, which is associated with a CH, performs intra-cluster communication. The CG, which is associated with a CH, interacts with neighboring clusters in inter-cluster communication. In vertical clustering, vertical cluster gateway (VCG) is introduced to enable interaction among UAVs in different clusters across different network planes, which is conveniently known as inter-plane communication.

References

1. Huang, X.L.; Ma, X.; Hu, F. Machine learning and intelligent communications. Mob. Netws. Appl. 2018, 23, 68–70.
2. Khan, M.F.; Yau, K.-L.A.; Noor, R.M.; Imran, M.A. Survey and taxonomy of clustering algorithms in 5G. J. Netw. Comput. Appl. 2020, 154, 201–221.
3. Song, Q.; Jin, S.; Zheng, F.-C. Completion time and energy consumption minimization for UAV-enabled multicasting. IEEE Wirel. Commun. Lett. 2019, 8, 821–824.
4. Oubbati, O.; Atiquzzaman, M.; Ahanger, T.; Ibrahim, A. Softwarization of UAV networks: A survey of applications and future trends. IEEE Access 2020, 8, 98073–98125.
5. Alzahrani, B.; Oubbati, O.; Barnawi, A.; Atiquzzaman, M.; Alghazzawi, D. UAV assistance paradigm: State-of-the-art in applications and challenges. J. Netw. Comput. Appl. 2020, 166, 102706.
6. Oubbati, O.; Mozaffari, M.; Chaib, N.; Lorenz, P.; Atiquzzaman, M.; Jamalipour, A. ECaD: Energy-efficient routing in flying ad hoc networks. Int. J. Commun. Syst. 2019, 32, e4156.
7. Kamel, M.; Hamouda, W.; Youssef, A. Ultra-dense networks: A survey. IEEE Commun. Surv. Tutor. 2016, 18, 2522–2545.
8. Shaikh, F.S.; Wismüller, R. Routing in multi-hop cellular device-to-device (D2D) networks: A survey. IEEE Commun. Tutor. 2018, 20, 2622–2657.
9. Chandrasekhar, V.; Andrews, J.; Gatherer, A. Femtocell networks: A survey. arXiv 2008, arXiv:0803.0952.
10. Li, Q.C.; Niu, H.; Papathanassiou, A.T.; Wu, G. 5G network capacity: Key elements and technologies. IEEE Veh. Technol. Mag. 2014, 9, 71–78.
11. Jiang, D.; Liu, G. An overview of 5G requirements. In 5G Mobile Communications; Springer: Cham, Switzerland, 2017; pp. 3–26.
12. Imran, A.; Zoha, A.; Abu-Dayya, A. Challenges in 5G: How to empower SON with big data for enabling 5G. IEEE Netw. 2014, 28, 27–33.
13. Habiba, U.; Hossain, E. Auction mechanisms for virtualization in 5G cellular networks: Basics, trends, and open challenges. IEEE Commun. Surv. Tutor. 2018, 20, 2264–2293.