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Cellular Assisted UAV Communication for Network-Centric Battlefield Operations with Seamless Link Handover

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Abstract - Unmanned Aerial Vehicles (UAVs) are increasingly employed for surveillance, reconnaissance, situational awareness and command and control support in network centric operational environments. Such missions require reliable communication despite continuous UAV movement across geographically distributed coverage regions. Cellular networks can provide wide area connectivity for UAVs where suitable infrastructure is available. However, maintaining connectivity during movement between cells remains a significant mobility management challenge. This paper investigates a mobility aware predictive handover framework for maintaining communication continuity of a high mobility UAV traversing multiple cellular coverage zones. The approach considers UAV position, speed and direction together with received signal strength, network latency, tower conditions and handover thresholds to anticipate cellular transitions before the serving link becomes unsuitable. A representative tactical communication scenario is considered in which a UAV operates across multiple cellular coverage regions while maintaining connectivity with command and operational elements through the cellular access and core network. The study establishes the operational relevance of predictive mobility aware handover for cellular assisted UAV communication and identifies challenges associated with contested environments including jamming, infrastructure loss, coverage gaps and cyber threats. Future development areas include artificial intelligence assisted handover, 6G tactical networks, UAV mesh relays and satellite fallback.

Key Words: UAV Communication, Cellular Networks, Predictive Handover, Mobility Aware Handover, LTE, 5G, Tactical Communication, Network Centric Operations.

1. INTRODUCTION

Unmanned Aerial Vehicles (UAVs) have become important platforms for missions requiring persistent surveillance, reconnaissance, rapid information collection and airborne sensing. In a network centric operational environment, a UAV can function as an information generating node by collecting surveillance imagery, video, coordinates, telemetry and other sensor information and transmitting these data toward command and operational elements. The operational value of such a platform therefore depends not only on its sensing capability but also on the availability and continuity of its communication link.

Modern tactical operations increasingly depend on rapid information exchange between geographically distributed users. UAVs can contribute to this information environment by providing an elevated sensing perspective and transmitting information to command headquarters and forward units. The communication requirements include timely transmission of surveillance data, situational awareness information, telemetry and command and control traffic.

Traditional communication links can face limitations associated with range, terrain masking and line of sight requirements. These limitations become more significant when the UAV operates over a large area and follows a dynamic trajectory. A communication architecture capable of supporting UAV mobility therefore needs to account for changes in the radio environment as the aircraft moves.

Cellular networks provide a potential complementary communication layer for UAV operations. The Third Generation Partnership Project (3GPP) has specifically studied enhanced Long Term Evolution (LTE) support for aerial vehicles, establishing that aerial users require consideration beyond conventional terrestrial user operation . Research on cellular connected UAVs has also identified the potential of cellular infrastructure while highlighting challenges related to coverage, interference and mobility management.

The use of cellular networks, however, introduces a mobility management challenge. A UAV moving through several cellular coverage regions may observe multiple strong neighboring cells and experience rapidly changing radio conditions. At sufficient altitude, line of sight conditions can also result in the UAV receiving signals from several cells simultaneously, increasing the complexity of cell selection and mobility management.

For a high mobility UAV, a handover mechanism that reacts only after the serving cell signal has deteriorated may not always provide sufficient time for a smooth transition. This motivates consideration of mobility aware predictive handover, in which information about the UAV movement is considered together with current network conditions.

The central research question addressed in this paper is: how can predictive mobility aware handover maintain communication continuity for a high mobility UAV traversing multiple cellular coverage zones in a network centric tactical environment?

The objective is not to replace dedicated tactical communication systems with cellular networks. Instead, the study considers cellular connectivity as a complementary communication layer and investigates how mobility aware handover can support continuity when a UAV moves between cellular coverage regions.

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The contribution is focused on the integration of three aspects: high mobility UAV communication, cellular mobility management and network centric tactical communication. A representative UAV mobility scenario from the project is used to illustrate practical communication transitions associated with movement between multiple cellular coverage regions.

2. RELATED WORK

2.1 Cellular Communication for UAVs

The integration of UAVs with cellular networks has received considerable research attention because existing cellular infrastructure can potentially provide wide area connectivity to aerial users. 3GPP TR 36.777, Enhanced LTE support for aerial vehicles, represents an important standardization effort addressing requirements and challenges associated with aerial users in LTE networks.

Zeng, Lyu and Zhang discussed the potential of cellular connected UAVs and identified communication, coverage, interference and mobility issues that must be addressed for reliable aerial connectivity. These studies establish cellular networks as a relevant technology for UAV connectivity while also highlighting the need for specialized mobility management.

2.2 Handover Challenges for Cellular Connected UAVs

Handover becomes particularly important when a UAV operates across multiple cellular coverage regions. Unlike a stationary or slowly moving ground user, a UAV may travel rapidly through coverage areas and may simultaneously observe several neighboring cells.

For an aerial drone connected to an LTE Advanced network, their measurements showed substantially higher handover frequency at aerial altitude than for ground users moving at the same speed, demonstrating that aerial mobility creates distinct handover challenges.

Research has also investigated the relationship between UAV mobility and cellular handover behavior and it was proposed that using handover, counts to estimate UAV velocity. This work later extended this idea to mobility state detection for cellular connected UAVs. These studies demonstrate that handover behavior itself can provide information about aerial mobility.

2.3 Mobility Aware and Predictive Approaches

Recent work has investigated handover aware UAV trajectory optimization, treating UAV movement and cellular connectivity as interconnected problems. Joint optimization of UAV trajectory and handover strategy has also been studied to maintain connectivity while avoiding excessive handover penalties. More recent research has directly examined explainable and physics aligned handover prediction for cellular connected UAV networks. This confirms that predictive handover is an active research direction rather than an unexplored concept. Accordingly, the present paper does not claim to introduce a fundamentally new prediction algorithm. It's contribution is to contextualize mobility aware predictive handover within a network centric tactical communication framework and to illustrate the concept using a representative multi cell UAV scenario.

3. CELLULAR ASSISTED UAV TACTICAL COMMUNICATION ARCHITECTURE

The proposed architecture considers the UAV as an airborne communication and sensing node connected through cellular infrastructure to a tactical network. The conceptual communication path is UAV, cellular access network, core network, command headquarters and forward operational users.

The UAV can generate surveillance data, video, telemetry, position information, sensor information and command related information. These information streams have different communication requirements. Surveillance video can require substantial data capacity, whereas command and control traffic places greater importance on responsiveness and continuity.

Cellular towers provide the radio access layer through which the UAV obtains connectivity. As the UAV moves, its radio relationship with the serving tower changes. The received signal from the current tower may decrease while another tower becomes a more suitable candidate.

The cellular core network provides connectivity between the radio access network and intended communication services or operational users. It provides the network path through which UAV generated information can reach command and operational elements.

The architecture supports a shared information environment in which UAV generated information can be made available to command headquarters, ground troops, artillery, electronic warfare units and other authorized users. Cellular connectivity should therefore be viewed as a complementary communication layer rather than a universal replacement for dedicated tactical radio or satellite communication systems.

Fig. 1: Network centric battlefield concept representation.

4. MOBILITY AWARE PREDICTIVE HANDOVER FRAMEWORK

4.1 Reactive Handover

In a conventional reactive handover process, the UAV remains associated with the serving cell until the communication condition approaches or crosses a predefined

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handover criterion. The sequence is: UAV remains connected to the serving cell; the UAV moves through the coverage region; serving cell signal conditions change; the handover criterion is reached; handover is initiated; and the UAV connects to the target cell. The limitation is that the decision is largely driven by a condition that has already developed. For a high mobility UAV, the time available between detection of degraded conditions and unacceptable communication quality may be relatively short.

4.2 Predictive Handover Concept

Predictive handover introduces information about the UAV movement into the decision process. Instead of waiting solely for the serving cell signal to become unsuitable, the system attempts to anticipate the UAV movement toward a coverage boundary and identify a suitable target cell before the serving link becomes unacceptable. The objective is not simply to perform handover earlier. The objective is to select an appropriate transition point based on both the current communication condition and the anticipated future position of the UAV.

4.3 Mobility and Network Parameters

UAV position indicates the current location relative to cellular coverage regions. UAV speed indicates how rapidly the aircraft is moving through the coverage environment. UAV direction provides information about the likely future coverage region. Received signal strength indicates the current radio link condition. Network latency provides an indication of communication responsiveness. Tower or network conditions can influence the suitability of a target cell. The handover threshold provides a reference for determining when continued association with the serving cell may become unsuitable.

4.4 Predictive Handover Decision Process

The conceptual process is: monitor the serving cell; monitor UAV position, speed and direction; estimate the future coverage region; identify a candidate cell; evaluate signal and network conditions; determine an appropriate handover point; transfer communication to the target cell; and continue monitoring. This process allows UAV mobility information to become part of the handover decision rather than treating handover solely as a reaction to signal degradation. The present study does not prescribe a machine learning model or optimization algorithm. Artificial intelligence assisted handover is considered a future extension.

5. REPRESENTATIVE UAV MOBILITY SCENARIO

The proposed framework is illustrated using a representative UAV mobility scenario derived from the project environment. The operational area is defined as 10 km by 10 km and contains three active cellular towers. The UAV operates at an altitude of 150 m and travels at 80 km/h using a dynamic mission path. LTE and 5G cellular connectivity are considered for the communication layer.

The purpose of this scenario is illustrative rather than statistically conclusive. It demonstrates how a UAV moving through multiple coverage regions creates a requirement for mobility management. The project material identifies signal strength, network latency, number of handovers and overall reliability as monitored indicators. The scenario considers an initial association with a cellular tower, movement through the operational area, changing signal conditions, approach toward a neighboring coverage region, handover consideration, transition to another cellular tower and continued communication as the mission progresses.

Parameter	**Representative value**
Operational area	10 km × 10 km
Number of cellular towers	3
UAV speed	80 km/h
UAV altitude	150 m
Cellular technology	LTE and 5G
UAV movement	Dynamic mission path

Table 1: Representative UAV mobility scenario parameters.

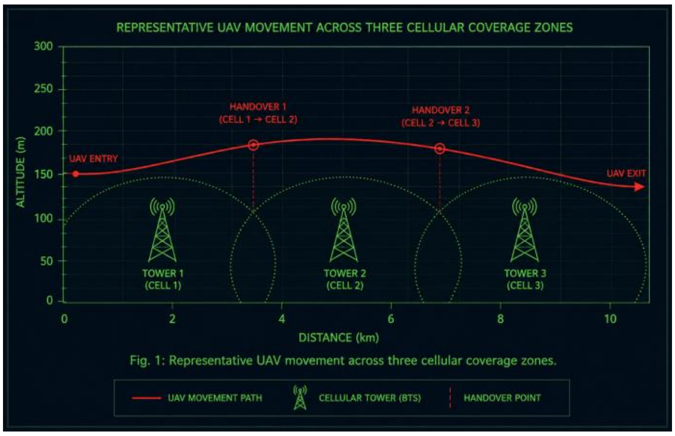

Fig. 2: Representative UAV movement across three cellular coverage zones.

6. ILLUSTRATIVE MULTI CELL UAV CASE STUDY

The representative scenario demonstrates the fundamental relationship between UAV mobility and cellular handover. As the UAV moves away from its serving tower, the received signal condition changes. At the same time, the signal from a neighboring tower can become increasingly favorable. The UAV consequently approaches a point at which continuing with the original serving cell may no longer be desirable.

A mobility aware handover framework can use this information before the current link becomes unacceptable. The process can be understood as UAV movement, changing radio conditions, changing serving cell signal, approach toward a coverage boundary, prediction of the next suitable cell, handover and continued cellular connectivity.

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The project material illustrates this behavior using three cellular coverage regions. The signal strength representation demonstrates that the UAV does not experience a constant radio environment throughout its mission. Instead, signal conditions change with movement and cell association. The latency representation illustrates the importance of maintaining communication responsiveness during cellular transitions. These observations are used here as illustrative evidence of the mobility management problem rather than as a statistically rigorous performance benchmark.

No claim is therefore made that the presented scenario proves a quantified improvement over conventional handover. A controlled comparison between reactive and predictive handover remains an important future experiment.

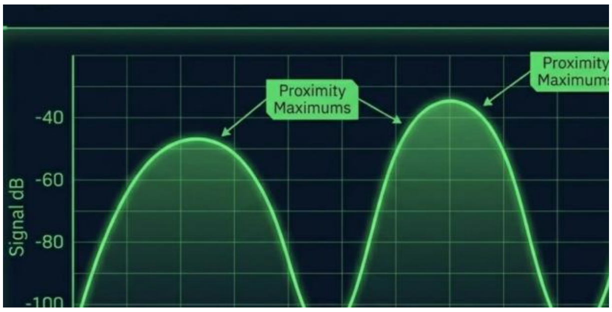

Fig. 3: Signal strength variation and illustrated handover execution points in the project scenario.

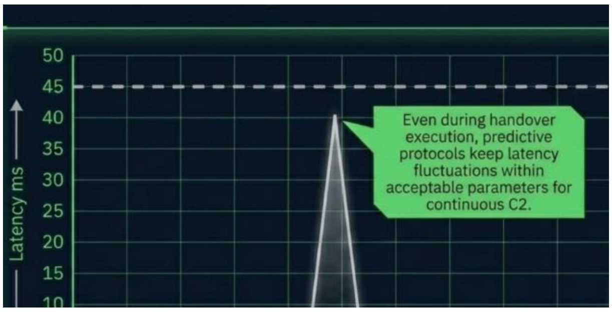

Fig. 4: Network latency variation during the illustrated mission scenario.

7. COMMUNICATION CONTINUITY AND OPERATIONAL SIGNIFICANCE

7.1 Surveillance

Continuous cellular connectivity can support transmission of surveillance information and video from the UAV toward command elements.

7.2 Situational Awareness

The UAV can provide position, sensor and surveillance information that contributes to the operational picture. Maintaining communication while the UAV changes serving cells helps reduce the possibility of information becoming temporarily unavailable because of a predictable coverage transition.

7.3 Command and Control

Command and control traffic requires responsive communication. A handover mechanism that anticipates movement can potentially reduce the likelihood that a UAV reaches an unacceptable serving cell condition before the transition is completed.

7.4 Information Dissemination

The communication path from UAV to cellular network to core network to command and operational users provides a mechanism for distributing UAV generated information. Effectiveness depends on cellular availability, network condition and the ability to maintain connectivity during movement.

7.5 Multiple UAV Operations

The same concept can potentially be extended to multiple UAVs operating within overlapping cellular coverage. However, the present study considers a representative single UAV scenario and does not experimentally evaluate multi UAV capacity, interference or network loading.

8. OPERATIONAL CHALLENGES AND LIMITATIONS

Intentional radio frequency interference or jamming can degrade or deny cellular connectivity. A predictive handover mechanism cannot maintain connectivity if all suitable cellular links in the operating area are disrupted.

Destruction or disabling of a cellular tower can create a coverage gap. Predictive handover requires an available target cell and therefore infrastructure loss can directly limit effectiveness. Cellular connectivity is geographically dependent, and areas without suitable coverage may require another communication technology.

The use of networked digital infrastructure introduces cybersecurity concerns. Protection of the communication network is therefore an important consideration for tactical deployment.

The present work is primarily a conceptual and operational framework supported by a representative UAV mobility scenario. It does not provide a controlled reactive versus predictive experiment, statistically repeated simulation study, quantitative packet loss measurements, a formal optimization algorithm, machine learning based prediction, multi UAV network scale evaluation, jamming experimentation, infrastructure destruction experimentation or cyberattack experimentation.

9. FUTURE SCOPE

Artificial intelligence and machine learning techniques can be investigated to predict UAV mobility and future cellular conditions. A future system could combine UAV trajectory, speed, direction, signal history, handover history, network latency and cell loading to estimate the most suitable target cell and transition point.

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Future cellular systems may provide enhanced support for highly mobile aerial users. Continued 3GPP work on aerial users indicates that UAV mobility and radio management remain active areas of standardization and research.

UAV mesh relay networks could provide an alternative communication path when terrestrial cellular infrastructure is unavailable. Multiple UAVs could potentially form an airborne communication layer.

Satellite communication can provide an additional communication layer when terrestrial cellular infrastructure becomes unavailable. A resilient architecture could therefore combine cellular, tactical radio, UAV relay and satellite communication.

An important experimental extension is a controlled comparison between reactive handover and predictive mobility aware handover under identical UAV trajectories. Potential evaluation parameters include handover interruption time, average latency, maximum latency, packet loss, handover frequency, communication outage duration and communication reliability.

10. CONCLUSION

This paper presented a mobility aware predictive handover framework for cellular assisted communication of a high mobility UAV operating in a network centric tactical environment. The central problem arises from the UAV continuous movement through geographically distributed cellular coverage regions. As the UAV moves, its serving cell signal and network conditions change, requiring timely mobility decisions to maintain communication continuity.

The proposed framework incorporates UAV position, speed and direction together with received signal strength, network latency, tower conditions and handover thresholds. This allows the handover process to consider both the current communication condition and the anticipated movement of the UAV.

A representative scenario based on the project environment considers a 10 km by 10 km operational area, three cellular towers, a UAV speed of 80 km/h, an altitude of 150 m and LTE and 5G connectivity. The scenario illustrates how UAV movement through multiple cellular coverage regions creates successive handover requirements and changing communication conditions.

The work is intentionally positioned as a mobility aware communication framework rather than a claim of a new handover algorithm. The supporting scenario demonstrates the operational relevance of predictive handover but does not constitute a controlled quantitative comparison against conventional reactive handover.

For tactical applications, cellular connectivity can serve as a complementary communication layer supporting surveillance, situational awareness and command and control information exchange. However, jamming, infrastructure destruction, coverage gaps and cyber threats can limit its availability. Future work should focus on quantitative reactive versus predictive comparisons, artificial intelligence assisted prediction, 6G tactical networks, UAV mesh relays and satellite fallback. A heterogeneous communication architecture combining these technologies may provide greater resilience for UAV communication in contested and infrastructure degraded environments.

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