**Contributions**

- Introduce an UAV-assisted Public Safety Network architecture of UE devices operating in a NOMA limited-interference environment.
- Define distinct UE roles with a set of critical UEs acting as clusterheads and the rest as PSN cluster members.
- Utilize a Minority Game theoretic mechanism for distributed UEs’ role selection.
- Introduce a clustering scheme based on reinforcement learning considering UEs’ physical proximity and battery life.
- Calculate the UAV/NeNB trajectory towards maximizing the energy availability of the cluster-head-acting critical UEs.
- Holistic utility function representing QoS prerequisites of UE devices.
- Distributed optimization problem of each device’s utility function to determine the optimal transmission power - Energy-efficient resource allocation framework.

**System Model**

- Uplink of a Non-Orthogonal Multiple Access (NOMA) wireless network in an $I \times I$ area.
- Multiple UE devices $M = \{1, \ldots, m, \ldots, M\}$ and a set of critical UEs $C = \{1, \ldots, c, \ldots, C\}$.
- One eNB-acting mobile UAV with velocity per axis: $(u^V_{AV}, u^V_{AV}, u^V_{AV})$.
- Two types of communication: D2D & D2eNB.
- Devices determine optimal uplink transmission power $P_{m}^*$.

**NOMA Wireless Setting**

- Sorted channel gain $G_{m,a}$ among devices $G_{m,a} \leq \ldots \leq G_{1,m}$.
- Sensed interference by device $m$ following Successive Interference Cancellation (SIC) $I_{m}(P_{m}) = \sum_{m \neq m+1} G_{m,a}P_{m+1} + I_0$.
- Signal-to-interference-plus-Noise-Ratio (SINR) $\gamma_{m}(P_{m}, P_{m}) = G_{m,a}P_{m}/I_{m}$.
- $m$ to receiver $k$.

**Minority Game for UEs’ Role Selection**

- Game Model: An odd number of agents compete for a shared resource, select between two options and the group that forms the minority wins $G_{MG} = \{M, \{A_{m}\}, \{R_{a_{m}}(m)\}\}$.
  - $M$ the set of UEs, $A_{m}$ the set of actions – role select.
  - $R_{a_{m}}(m)$ the payoff the UE $m$ receives after selecting role $a_{m}$.
  - Cutoff value $C_{th}$ denoting desired number of clusterheads – the minority group.
  - During each game round $\{2\}$ UEs chose between two possible actions $a_{m}$.
  - Attendance $c_{l}$, the collective sum of UEs’ actions – population of minority group.
  - Shared resource: Location of the UAV.
    - If $c_{l} \leq C_{th}$, the $c_{l}$ clusterheads are considered winners.
    - If $c_{l} > C_{th}$, the members are considered Minority Game winners if the increased number of chs leads to poor UAV positioning and thus poor energy efficiency.
  - After action selection the UAV (central MG entity) broadcasts the winning choice.
  - Received Payoff: $P_{l_{m}}(m) = \begin{cases} 1, & \text{if } c_{l} \leq C_{th}, \\ 0, & \text{otherwise} \end{cases}$.

**Reinforcement Learning-based Clustering**

- Reward probability $r_{l_{m}}(m)$ to reflect the competitiveness of each ch $c$ as perceived from the member UE $m$ and is given by:
  $\[r_{l_{m}}(m) = \frac{E[l_{m}]}{\mathbb{E}[l_{m}]}, (d_{m,c})^{2}, \frac{1}{\sum_{c} d_{m,c}^{2}}\]$
- Learning automata action probability $P_{l_{m}}(m)$, device $m$, selecting ch $c$.
- For a device $m$ associated with ch $c$, the probability of choosing the same ch:
  $\[P_{l_{m}}(m) = P_{l_{m}}(c-1) + b \cdot r_{l_{m}}(m) \cdot (1 - P_{l_{m}}(c-1))\]$
- The probability to change to a new clusterhead $c'$:
  $\[P_{l_{m}}(m) = P_{l_{m}}(c-1) - b \cdot r_{l_{m}}(m) \cdot P_{l_{m}}(c-1)\]$

**UAV Positioning & Resource Management**

- The UAV performs a uniform motion towards each 3D space axis within a bounded area. The specific position for each timeslot aims to extend the energy availability of the clusterheads:
  $\\left\{ \frac{x_{AV}}{x_{AV}}, \frac{y_{AV}}{y_{AV}}, \frac{z_{AV}}{z_{AV}} \right\} = \arg \max \left( \sum_{c} E[l_{m}^{c}] - \sum_{c} \gamma_{c}(P_{c}) \right) \text{ s.t. } 0 \leq \frac{x_{AV}}{x_{AV}} - \frac{y_{AV}}{y_{AV}} \leq \frac{x_{AV}}{x_{AV}} + \frac{y_{AV}}{y_{AV}} \leq \frac{1}{2}$
  $\frac{y_{AV}}{y_{AV}} - \frac{z_{AV}}{z_{AV}} \leq \frac{y_{AV}}{y_{AV}} + \frac{z_{AV}}{z_{AV}} \leq \frac{1}{2}$
  $\frac{z_{AV}}{z_{AV}} \leq \frac{x_{AV}}{x_{AV}} - \frac{y_{AV}}{y_{AV}} \leq \frac{x_{AV}}{x_{AV}} + \frac{y_{AV}}{y_{AV}} \leq \frac{1}{2}$

**Performance Evaluation**

- The NOMA limited UE’s Utility Function $U_{m}(P_{m}) = W : f_{m}(\gamma_{m})$.
- Maximum $\gamma_{m}$, the probability of choosing the same ch.
- The equations for unique optimal uplink transmission power $P_{m}^*$.

**Unique Optimal Uplink Transmission Power**

**Theorem 1** The non-cooperative power control game $G$ has a unique Nash equilibrium point $P_{m}^* = \{P_{m}, P_{m}^*, \ldots, P_{M}^*\}$.

**Conclusion**

- The performance benefits of the proposed system are observed through simulations.
- The proposed system architecture demonstrates significant energy efficiency enhancements.

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**Further Reading:**