UAV Relay in VANETs Against Smart Jamming with Reinforcement Learning

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Outline

- Jamming attacks in vehicular ad-hoc networks (VANETs)
- Unmanned aerial vehicles (UAV)-aided VANETs transmission against jamming
- Reinforcement learning techniques
- Hotbooting policy hill climing (PHC)-based relay strategy
- Simulation results
- Conclusion

Jamming Attacks in VANETs

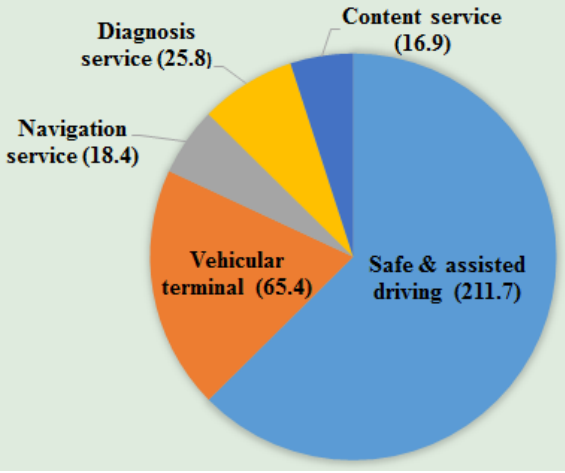
- Jammers send faked or replayed signals to block the communication of onboard units (OBUs) with another OBU or roadside units (RSUs) in VANETs

First car recall event

Control smart vehicles such as BMW, Mercedes and Chrysler, 2013

Fail the vehicle brake and shutdown the engine of Jeep's system, 2015

Tencent Cohen Laboratory controls Tesla vehicular system, 2016

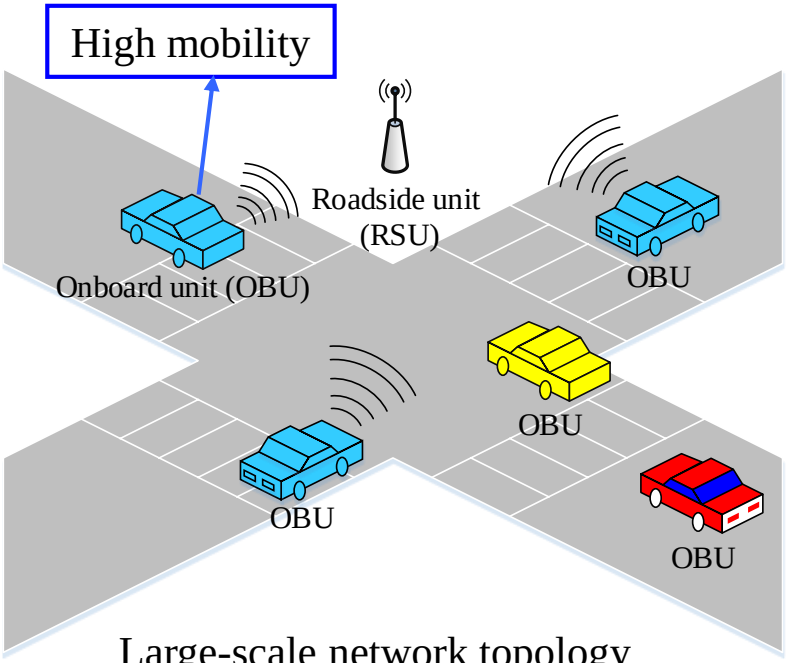


2020 VANETs market of China (billion dollars)

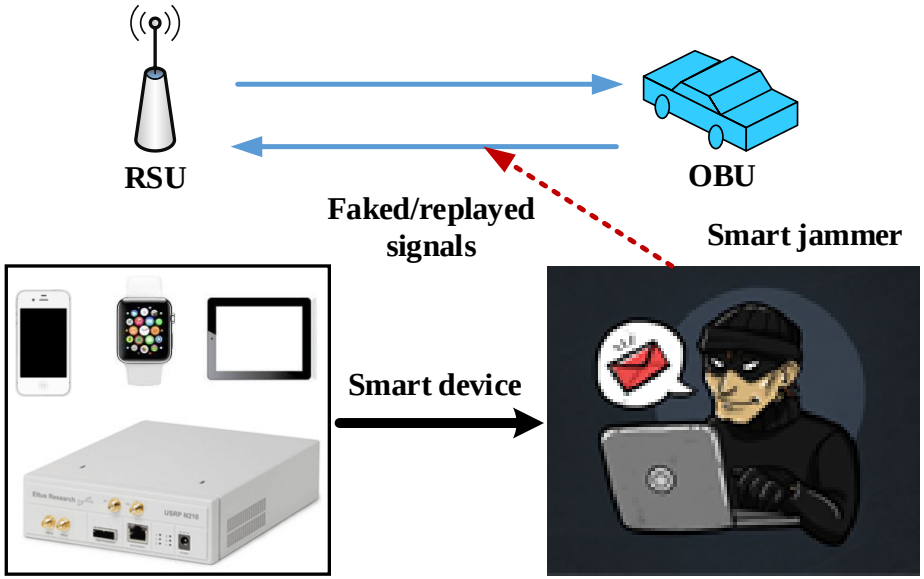
Remote jamming attack in VANETs

Smart Jamming in VANETs

- Apply smart radio devices such as USRPs and WARPs to observe the ongoing transmission and eavesdrop the VANET control channel
- Analyze the anti-jamming transmission policy of VANETs
- Flexibly choose the jamming policy against VANETs

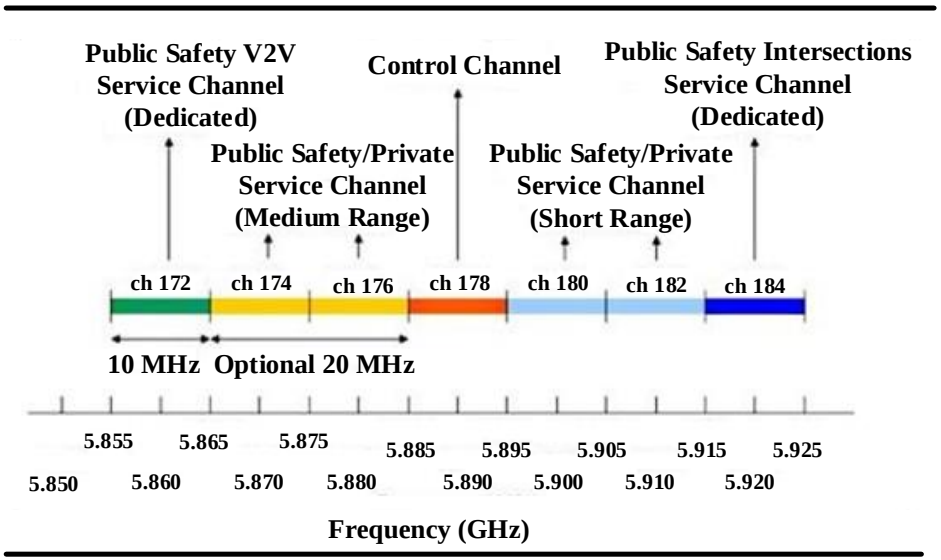


Large-scale network topology

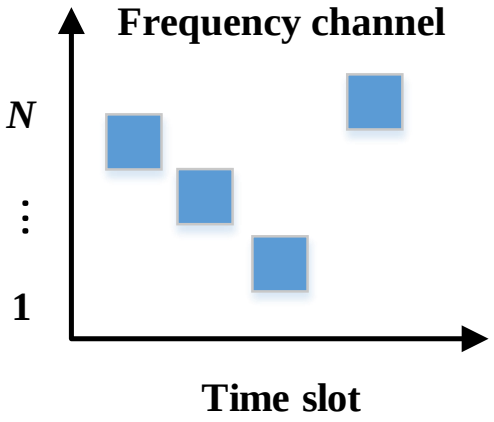


Jamming Resistance of VANETs

- Frequency hopping-based anti-jamming techniques are not applicable in VANETs due to the restricted bandwidth resource
- Ambient noise immunity based anti-jamming transmission to improve the packet delivery rate in VANETs [Puñal'12]
- Anti-jamming hideaway strategy determines whether to keep silent based on the packet transmission ratio [Azogu'13]

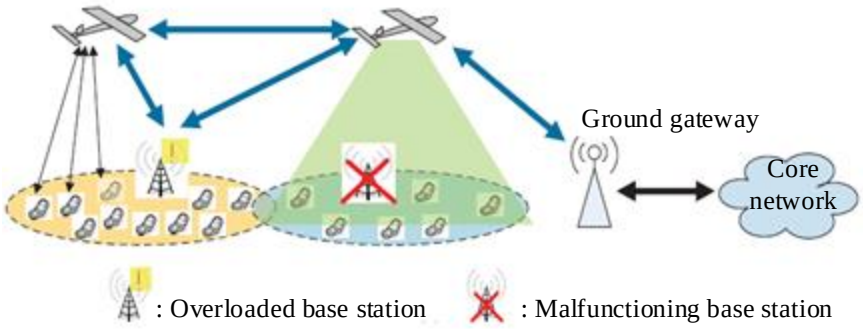


IEEE 802.11p

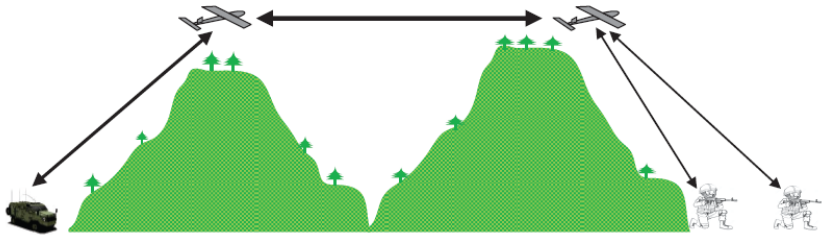


UAV-Aided VANETs

- UAVs relay messages for VANETs to extend coverage and improve network connectivity
  - Faster to deploy
  - Better channel states connecting OBUs: line-of-sight links & smaller path-loss exponents
- UAVs have been used to relay mobile messages for ground terminals to maximize the capacity of VANETs [Dixon'12]
- UAVs relay vehicles' alarm messages regarding lethal attacks to improve the intrusion detection accuracy in VANETs [Sedjelmaci'16]



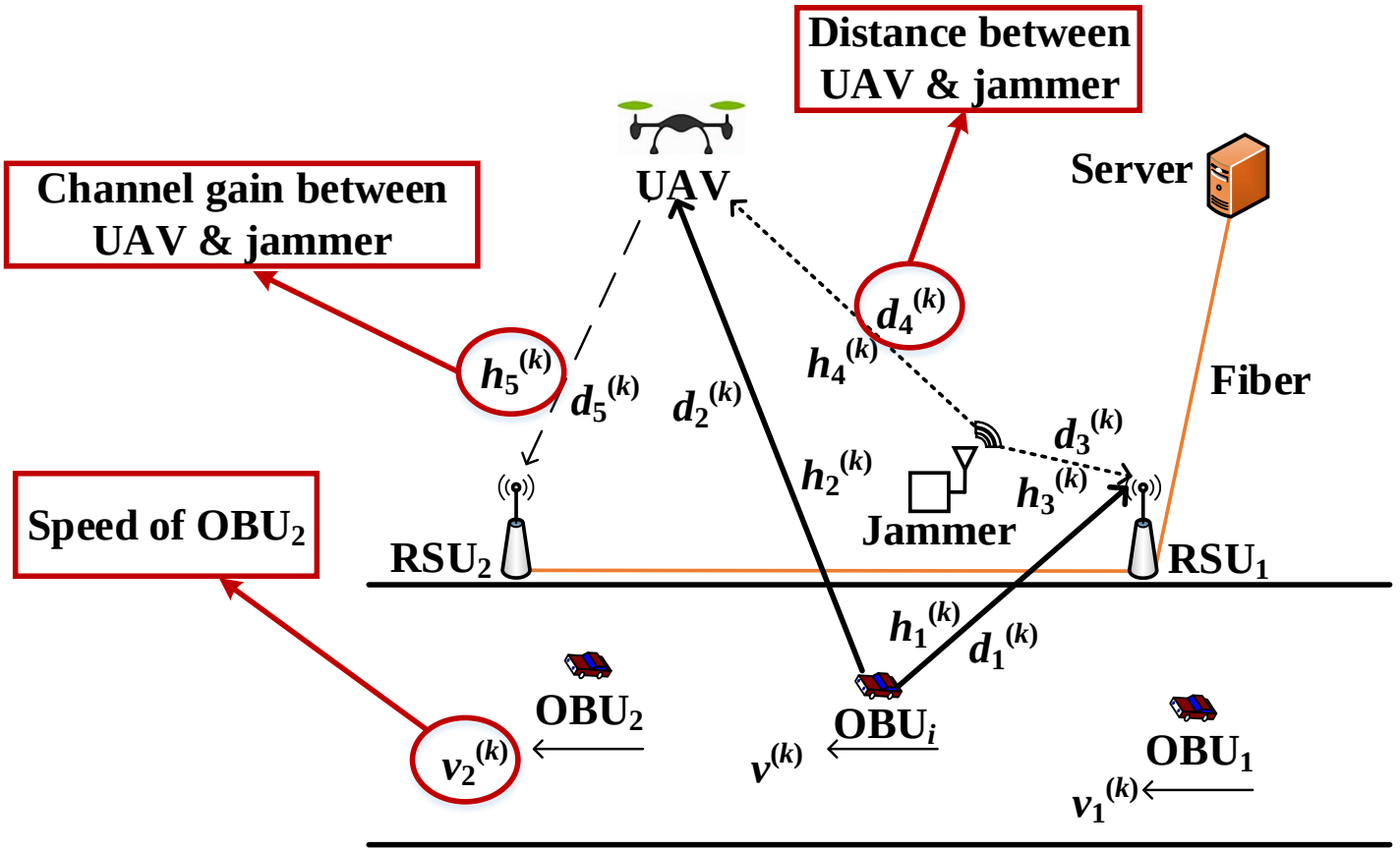
UAV-aided ubiquitous coverage



UAV-aided relaying

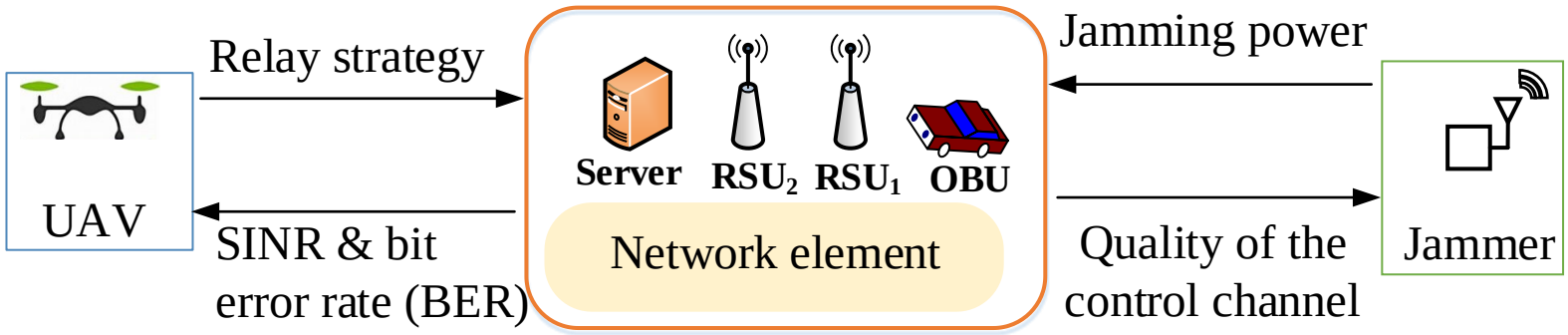
Network Model

- OBU aims to send a message to a server via RSU_1 or UAV
- Jammer sends faked or replayed signals to block the OBU-RSU_1 link
- UAV assists RSU_1 to relay the OBU message to RSU_2
  - RSU_2 is far away from the jammer



Anti-jamming Transmission Game

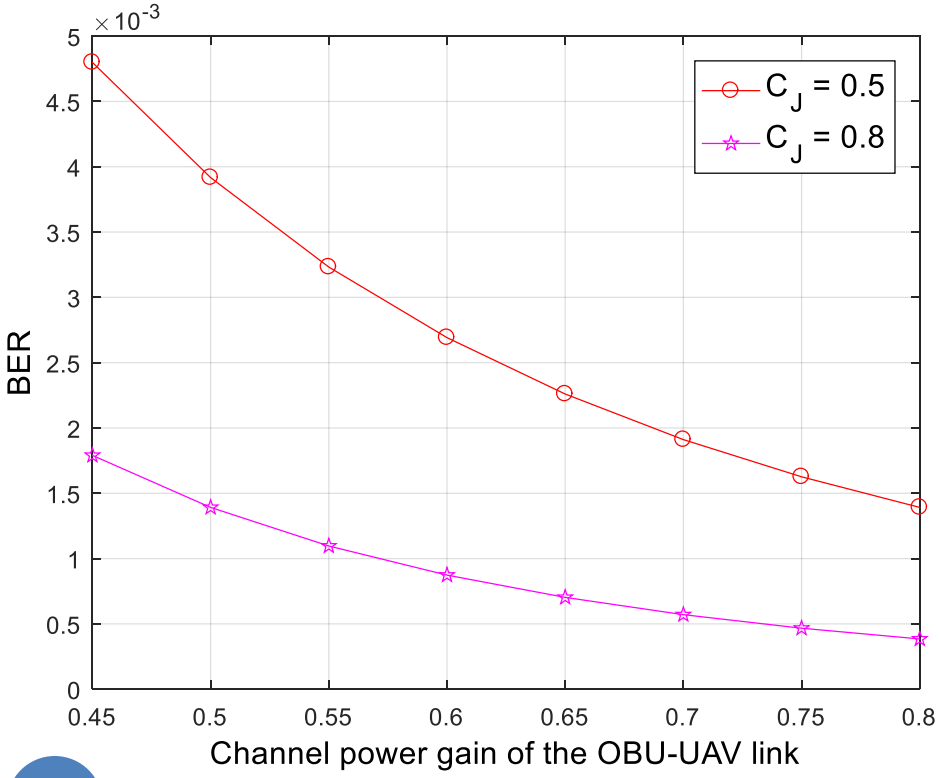
- UAV assists the VANET to improve the transmission quality with less overall transmission costs
- Jammer aims to degrade the VANET communication performance with less jamming costs
- Utility of the UAV: Overall transmission cost & BER of the signal received by the server

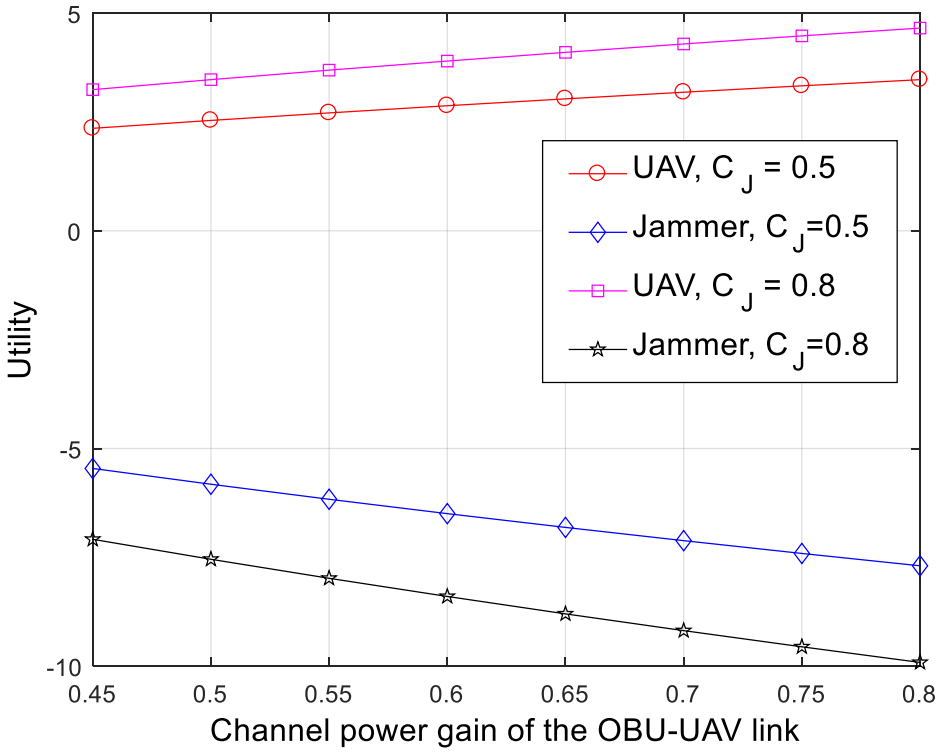


X. Lu, D. Xu, L. Xiao, L. Wang, and W. Zhuang, "Anti-jamming communication game for UAV-aided VANETs," Globecom, 2017.

NE of the Game

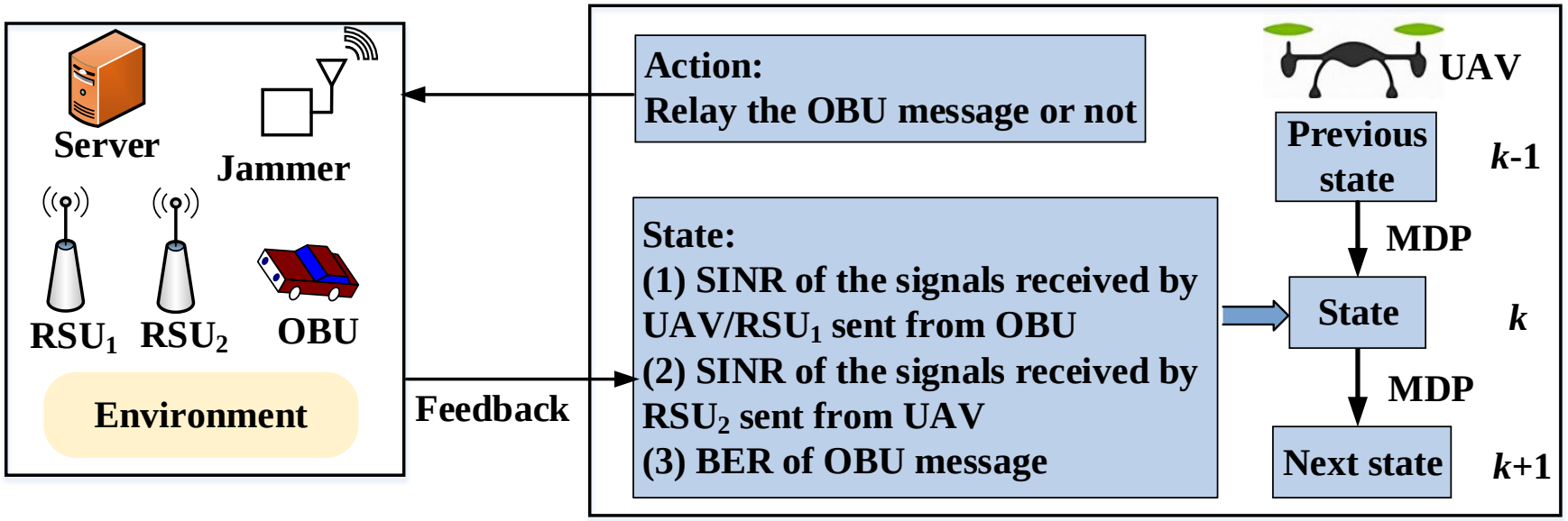
- Nash equilibrium (NE): UAV and jammer can not increase its utility by unilaterally leaving the NE strategy





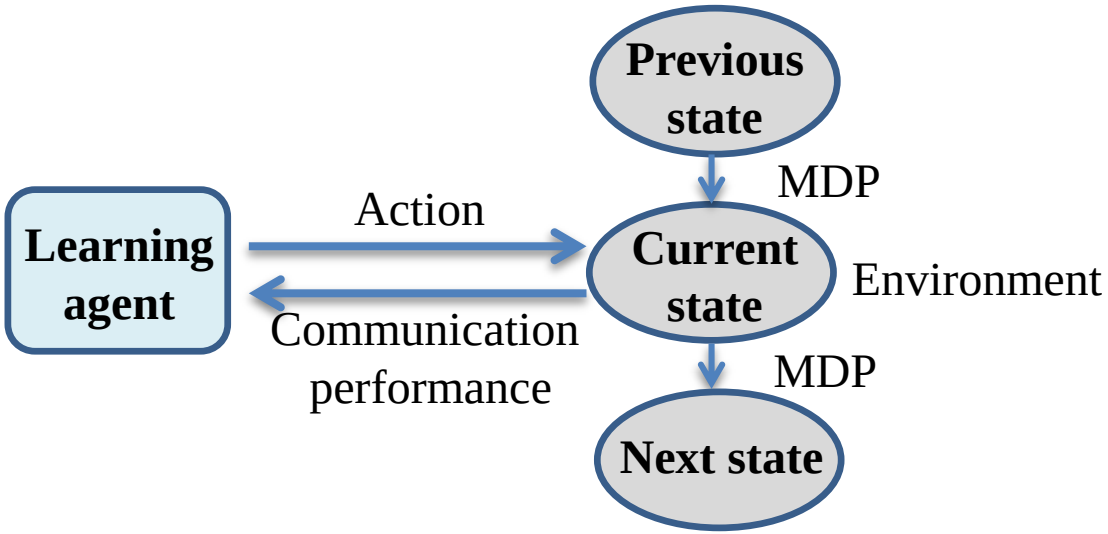
Dynamic Anti-Jamming Trans Game

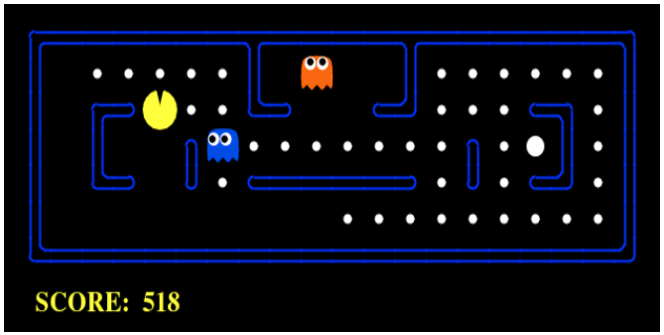
- UAV relay process in the dynamic game can be viewed as a Markov decision process (MDP)
- Determine the relay strategy in the dynamic VANET game without being aware of the jamming model and the network model



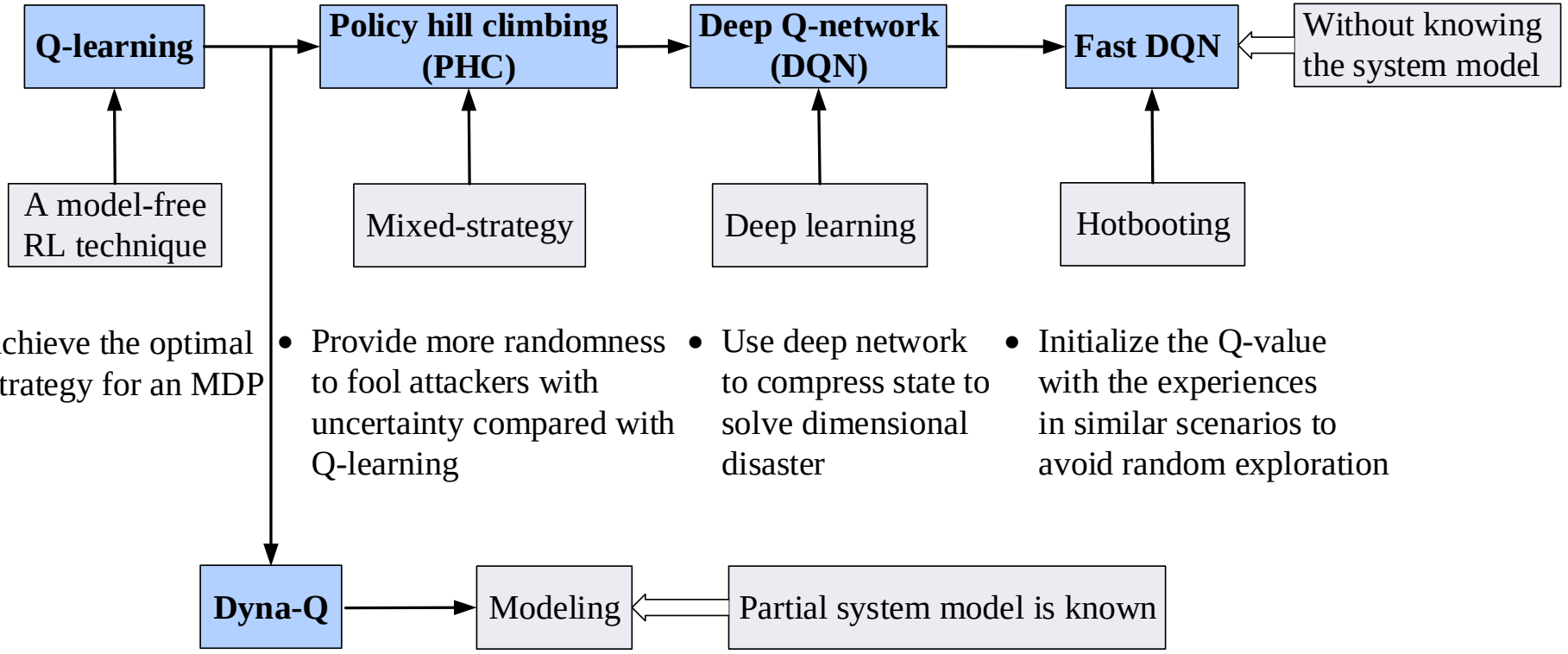
Reinforcement Learning

- Reinforcement learning such as Q-learning can achieve the optimal strategy for MDP with finite states





Typical RL Algorithms



- Achieve the optimal strategy for an MDP
- Provide more randomness to fool attackers with uncertainty compared with Q-learning
- Use deep network to compress state to solve dimensional disaster
- Initialize the Q-value with the experiences in similar scenarios to avoid random exploration

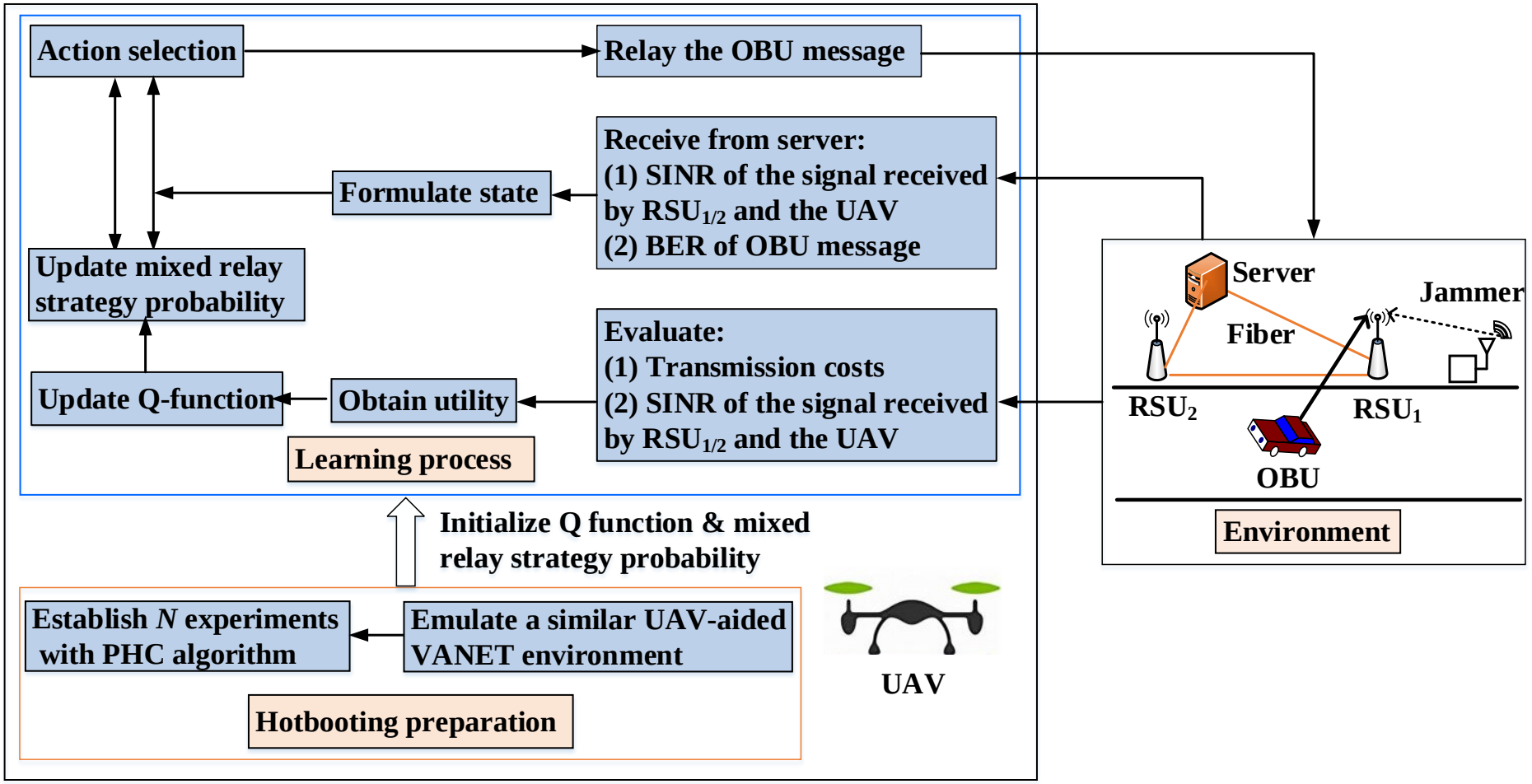
RL-based Anti-Jamming Communication

RL Techniques	Strategy	Constraints	Performance
Q-learning	Channel selection	Bandwidth	Communication gains minus cost & loss [Wu'12]
			Successful transmission rate [Gwon'13]
			Computation complexity [Aref'17]
			Energy cost & packet delivery rate [Dai'17]
	Power control	Static networks	Signal-to-interference-plus-noise ratio (SINR) [Xiao'15]
	Offloading rate	Computation	Attack rate [Xiao'16]
WoLF-PHC	Power control	Static networks	SINR [Xiao'15]
DQN	Channel selection Mobility	Bandwidth Network scale	SINR [Han'17]

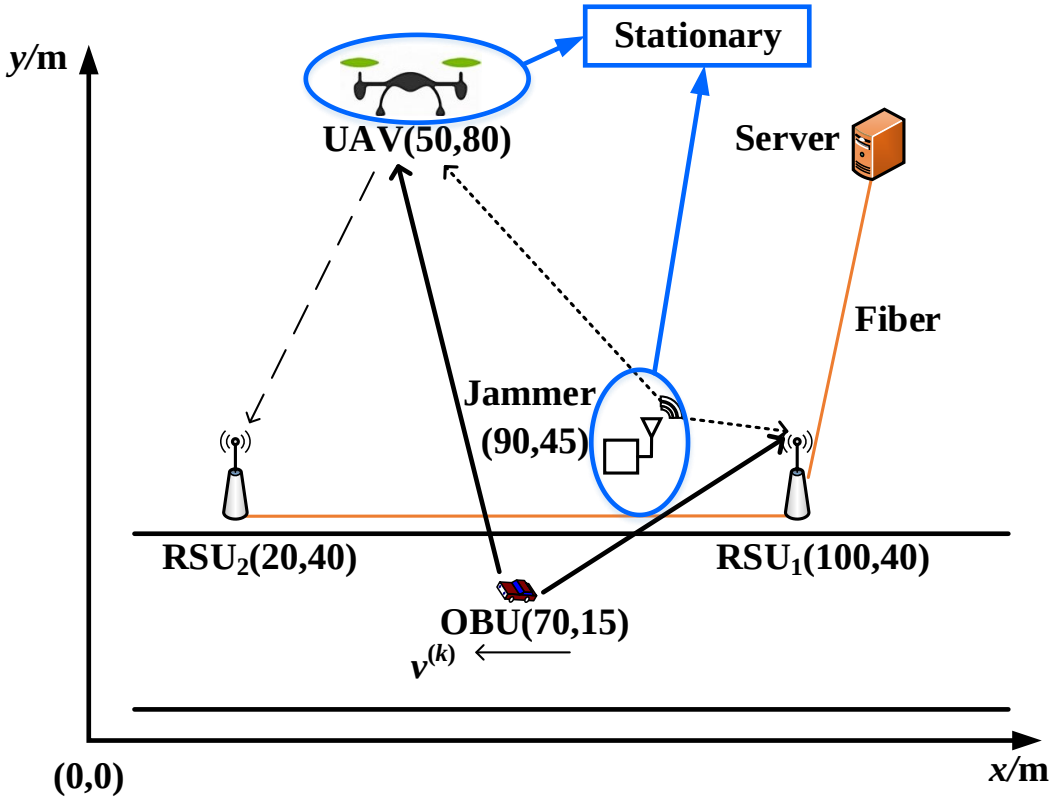
Hotbooting PHC-based Relay Strategy

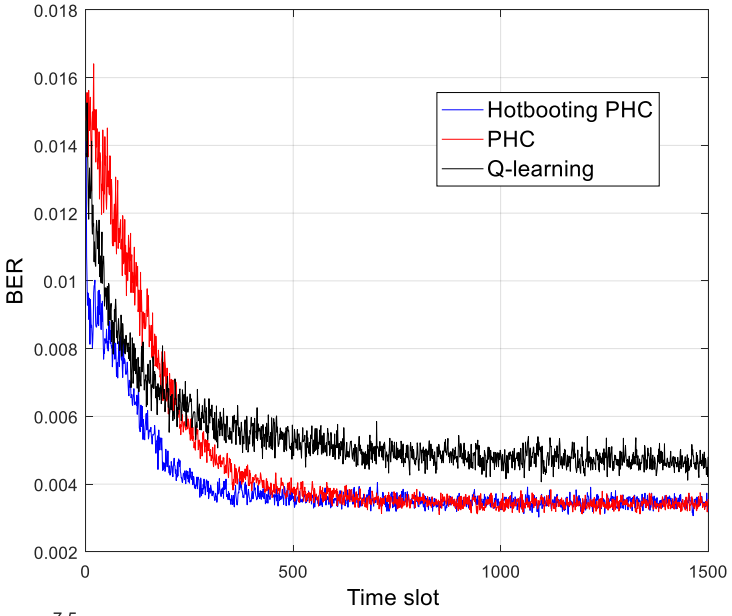
- PHC: Extension of Q-learning in mixed-strategy games to derive the optimal policy for MDP
  - Provide more randomness in the UAV relay strategy to fool the jammers
  - Avoid being induced by the jammer to a specific relay strategy
- Hotbooting: Transfer learning initializes the Q-value for each action-state pair with the experiences in similar anti-jamming UAV-aided VANET transmission scenarios
  - Decrease the random explorations at the beginning
  - Accelerate the learning speed in the dynamic game

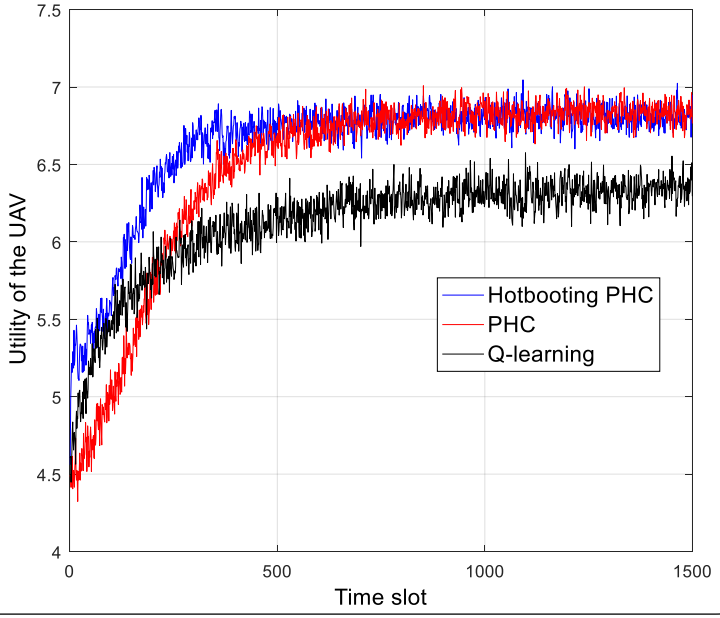
UAV Relay Protocol



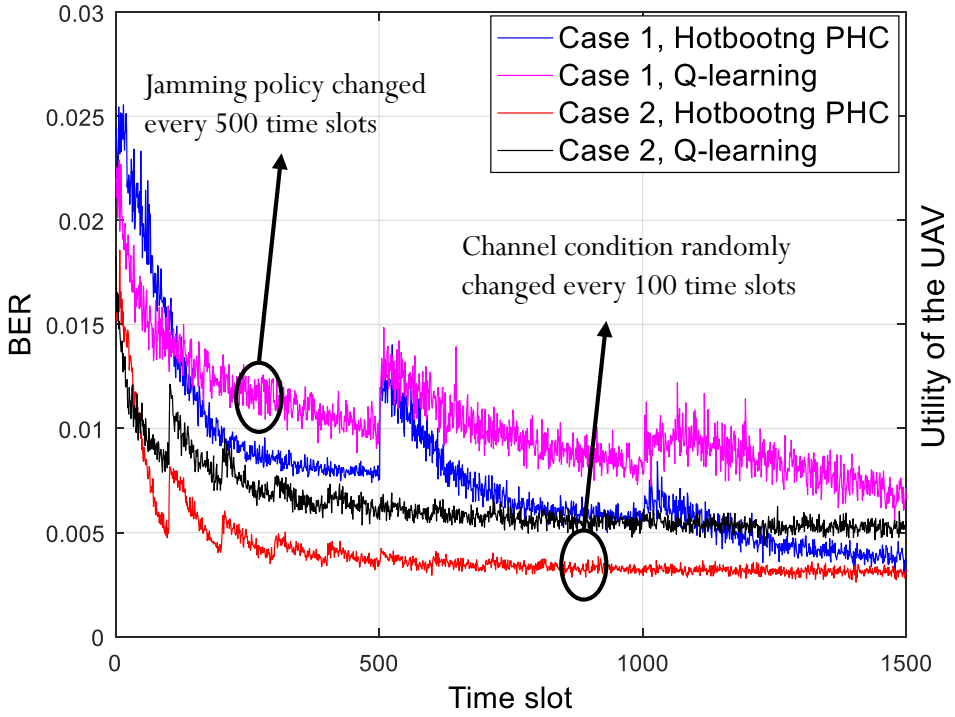
Simulation Results

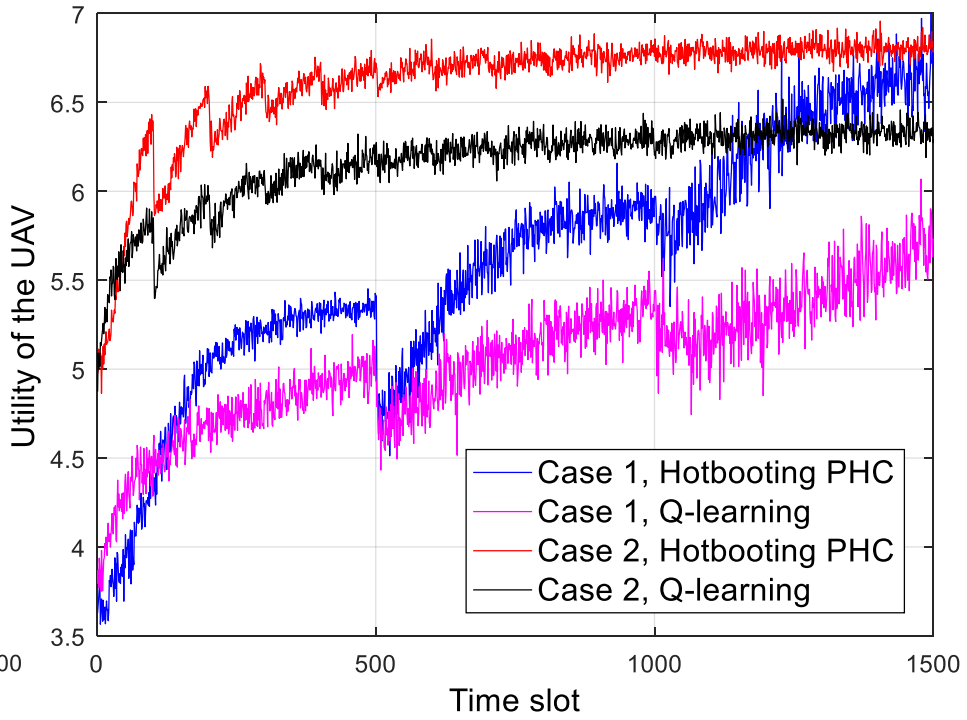






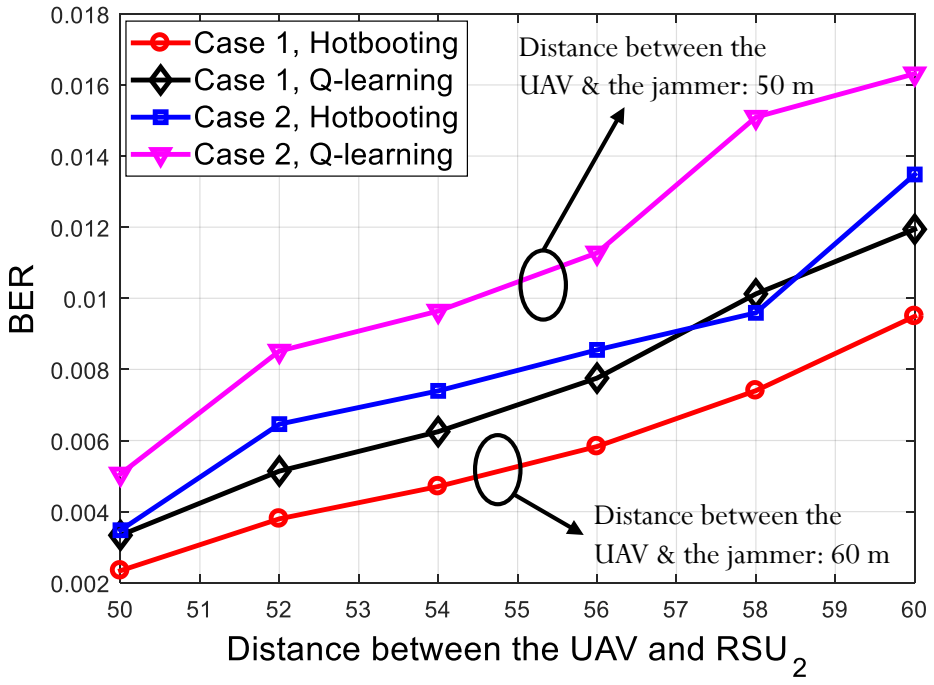
Simulation Results (cont.)

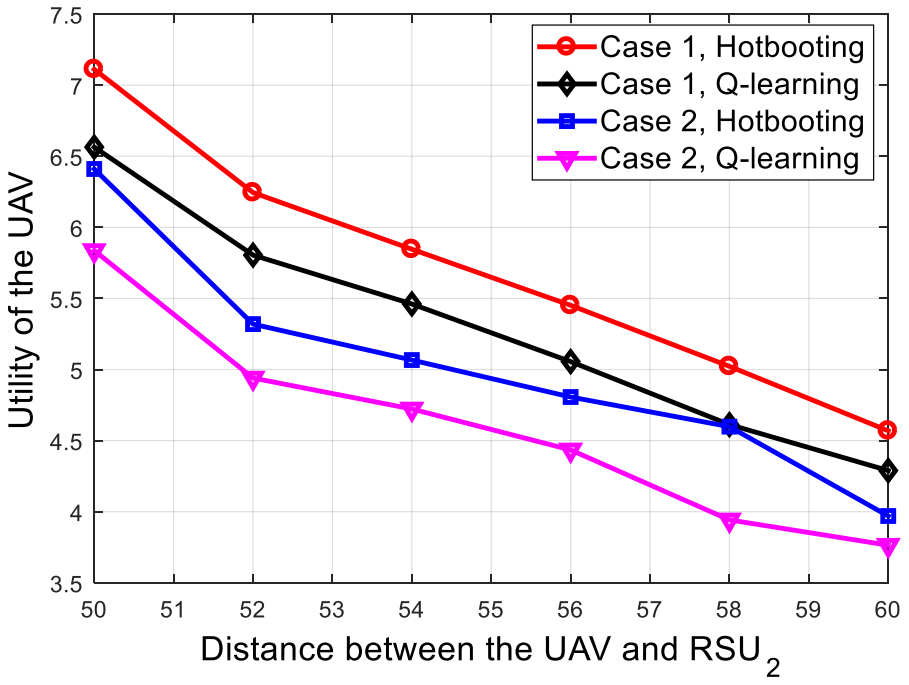




L. Xiao, X. Lu, D. Xu, Y. Tang, L. Wang, and W. Zhuang, "**UAV Relay in VANETs Against Smart Jamming with Reinforcement Learning**," IEEE Transactions on Vehicular Technology, under review.

Simulation Results (cont.)





- The transmission performance depends on the UAV location

Conclusion

- We have formulated a UAV relay game for UAV-aided VANETs, providing the NEs of the game
- We have proposed a hotbooting PHC-based UAV relay strategy to resist jamming attacks in VENETs without being aware of the jamming model and the network model
- Future work
  - Improve the game model by incorporating more jamming and defense details
  - Accelerate the learning speed of the relay strategy to implement in practical VANETs
  - Provide robustness against utility evaluation errors with incomplete state information

Questions?

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