TABLE II
EXECUTION TIMES OF COMPARED MAB ALGORITHMS IN THE TWO SCENARIOS.

Scenario 1 (mmWave-enabled D2D NDS)					**Scenario 2 (UAV-based network gateway selection)**		
Number of devices	**UCB**	**EA-UCB**	**Lin-UCB**	**EA-LinUCB**	**Number of UAVs**	**MP-BA-UCB**	**MP-BA-EXP3**
20	0.1 ms	0.1ms	0.3ms	0.3ms	10	1.5ms	1.7ms
40	0.1 ms	0.1ms	0.4ms	0.4ms	20	1.6ms	1.8ms
60	0.1ms	0.1ms	0.6ms	0.6ms	30	1.7ms	1.9ms
80	0.2 ms	0.2 ms	0.8ms	0.8ms	40	1.9ms	2ms
100	0.2 ms	0.2ms	0.9ms	0.9ms	60	2.0ms	2.1ms

However, as the number of access UAVs is increased beyond the number of ariel UAVs, i.e., 20 UAVs, a high interference is experienced by access UAVs. Note that MP-BA-UCB achieves much better performance than MP-BA-EXP3. The poor aerial gateway selection policy of MP-BA-EXP3 can be explained by its nearly equal weights assignment to the UAVs during each trial. To analyze the performance of the adopted MAB algorithms, the analysis of regret (the cumulative rewards of the best arm in hindsight) is useful; however this is beyond the scope of this article. For simplicity, consider that the algorithm to be successful if its regret is $\mathcal{O}(T)$ after T trials (meaning that the average regret per trial converges to zero). The adopted MAB models with UCB or TS have $\mathcal{O}(logT)$ regret bounds.

The execution times of the MAB-based approaches utilized in the two scenarios are summarized in Table II. We recorded the MATLAB R2020 b execution time of these MAB techniques against different numbers of devices and UAVs, respectively. The utilized machine specifications consist of an Intel core i7-8565U CPU (Central Processing Unit) and 8 GB (Giga Bytes) RAM (Random Access Memory). From the table, execution times of the proposed algorithms are within milliseconds range suited to 6G millisecond latency. On the other hand, when traditional Integer Linear Programming (ILP)-based optimization solver is used for the mmWave topology, the execution time is in the order of seconds for 10 nodes and is not attempted for higher number of nodes in [14]. Similarly, for scenario 2, the execution time of a traditional application of an optimization algorithm also results in execution times of order of seconds and exponentially increases for an increase of coverage areas [15]. Thus, the high execution times of the traditional optimization algorithms reflect a high time complexity in contrast with those of the considered MAB techniques. This corroborates with our proposed optimal policy selector's choice of deploying the aforementioned MAB models for fast, sequential decision making in the considered scenarios.

V. CHALLENGES AND FUTURE DIRECTIONS

In this section, we describe the challenging research topics for further investigation in softwarized intelligence, particularly using ultra-fast policy selection and deployment in 6G networks, by exploiting MAB frameworks and similar sequential/online algorithms.

- Resource allocation in Low Power Wide Area Network (LoRAWAN) networks, Non-Orthogonal Multiple Access (NOMA), underwater relay selection and routing, and underlay D2D communication can greatly benefit from using relevant MAB variants to suit a diverse range of scenarios. Also, the on-demand controller's decisions in the proposed softwarized network can be greatly improved for routing information by utilizing MABs with ideal policies.
- Reflecting Intelligent Surfaces (RIS) and meta-learning are two attractive, relatively new areas where sequential learning algorithms may be highly effective. RIS is a two-dimensional surface composed of several passive reconfigurable meta-material elements, which reflect the incident signal by introducing a controllable phase shift. Recently, RIS has been used in communication networks for several purposes, including coverage enhancement, relaying, and physical-layer security. However, there are several challenges for achieving the potential of such structure, where AI-based techniques, particularly on-demand deployment of MAB models, can help learn the proper phase shift for each element under the discrete-phase shift assumption.
- Meta-learning may be a helpful technique in inductive bias's selection automation. It leverages valuable information or active observations from tasks that are expected to be related to the future tasks of interest. Such learning can facilitate the AI model training with a significantly lower amount of data and time. Hence, the meta-learning policies for MAB may be effectively leveraged for satisfying the ultra-low latency requirement of 6G network nodes.

VI. CONCLUSION

Intelligent decision-making is anticipated to be a key embedded feature in the upcoming 6G networks that will realize innovative future applications. Since these services have ultra-reliable requirements easily impacted by varying network dynamics, on-demand ultra-fast learning techniques emerge as a formidable research challenge. In this article, we addressed this challenge, and proposed a softwarized network consisting of an on-demand policy selector that considers the ongoing network dynamics and accordingly chooses the best intelligence module for that particular network setting. Unlike the classical optimization and supervised learning methods, online/sequential learning techniques such as MAB algorithms with different policies, were illustrated to be viable sequential learning techniques by the proposed on-demand selector for

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6G node deployment. A use case with two scenarios was presented comprising NDS in a D2D network and aerial gateway selection in a UAV network, respectively. Extensive computer-based simulation results demonstrated that the selected MAB variant for both scenarios significantly outperforms both the conventional techniques and other MAB variants. Thus, the reported results clearly indicate the optimal policy selection capability of our proposed on-demand selector. As a caveat, it is worth noting that for deploying the models in an on-demand manner, there could be some connectivity issues causing the AI models not to be timely updated that may cause the target routers/network nodes to be rendered dysfunctional. To combat such a corner case, we may assume a default, basic functionality of programmable routers to cope with such scenarios. How to optimally generalize such a default functionality is left open as a future work for 6G softwarized networks and programmable routers.

REFERENCES

[1] W. Wu, N. Cheng, N. Zhang, P. Yang, W. Zhuang, and X. Shen, "Fast mmwave beam alignment via correlated bandit learning," *IEEE Transactions on Wireless Communications*, vol. 18, no. 12, pp. 5894–5908, 2019.
[2] X. Pan, X. Wang, B. Tian, C. Wang, H. Zhang, and M. Guizani, "Machine-learning-aided optical fiber communication system," *IEEE Network*, vol. 35, no. 4, pp. 136–142, 2021.
[3] S. Hashima, K. Hatano, H. Kasban, and E. Mahmoud Mohamed, "Wi-Fi assisted contextual multi-armed bandit for neighbor discovery and selection in millimeter wave device to device communications," *Sensors*, vol. 21, no. 8, p. 2835, 2021.
[4] E. M. Mohamed, S. Hashima, K. Hatano, S. A. Aldossari, M. Zareei, and M. Rihan, "Two-hop relay probing in WiGig device-to-device networks using sleeping contextual bandits," *IEEE Wireless Communications Letters*, vol. 10, no. 7, pp. 1581–1585, 2021.
[5] E. M. Mohamed, S. Hashima, A. Aldosary, K. Hatano, and M. A. Abdelghany, "Gateway selection in millimeter wave UAV wireless networks using multi-player multi-armed bandit," *Sensors*, vol. 20, no. 14, p. 3947, 2020.
[6] D. Li, S. Wang, H. Zhao, and X. Wang, "Context-and-social-aware online beam selection for mmwave vehicular communications," *IEEE Internet of Things Journal*, vol. 8, no. 10, pp. 8603–8615, 2021.
[7] Y. Xing, Y. Qian, and L. Dong, "A multi-armed bandit approach to wireless information and power transfer," *IEEE Communications Letters*, vol. 24, no. 4, pp. 886–889, 2020.
[8] J. Zhang, J. Tang, and F. Wang, "Cooperative relay selection for load balancing with mobility in hierarchical WSNs: A multi-armed bandit approach," *IEEE Access*, vol. 8, pp. 18 110–18 122, 2020.
[9] W. Xia, T. Q. S. Quek, K. Guo, W. Wen, H. H. Yang, and H. Zhu, "Multi-armed bandit-based client scheduling for federated learning," *IEEE Transactions on Wireless Communications*, vol. 19, no. 11, pp. 7108–7123, 2020.
[10] X. Xu, M. Tao, and C. Shen, "Collaborative multi-agent multi-armed bandit learning for small-cell caching," *IEEE Transactions on Wireless Communications*, vol. 19, no. 4, pp. 2570–2585, 2020.
[11] S. Ali, A. Ferdowsi, W. Saad, N. Rajatheva, and J. Haapola, "Sleeping multi-armed bandit learning for fast uplink grant allocation in machine type communications," *IEEE Transactions on Communications*, vol. 68, no. 8, pp. 5072–5086, 2020.
[12] C. Wang, J. Yang, H. He, R. Zhou, S. Chen, and X. Jiang, "Neighbor cell list optimization in handover management using cascading bandits algorithm," *IEEE Access*, vol. 8, pp. 134 137–134 150, 2020.
[13] H.-A. Tran, S. Souihi, D. Tran, and A. Mellouk, "MABRESE: A new server selection method for smart SDN-based CDN architecture," *IEEE Communications Letters*, vol. 23, no. 6, pp. 1012–1015, 2019.
[14] G. H. Sim, M. Mousavi, L. Wang, A. Klein, and M. Hollick, "Joint relaying and spatial sharing multicast scheduling for mmWave networks," in *2020 IEEE 21st International Symposium on "A World of Wireless, Mobile and Multimedia Networks" (WoWMoM)*, 2020, pp. 127–136.
[15] J. Sabzehali, V. K. Shah, Q. Fan, B. Choudhury, L. Liu, and J. H. Reed, "Optimizing number, placement, and backhaul connectivity of multi-UAV networks," *arXiv preprint arXiv:2111.05457*, 2021.

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