Demo: NOMAD: An Edge Cloud Platform for Hyper-Responsive Mobile Apps

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Fast access to backend services is crucial for many mobile apps. For example, emerging augmented-reality devices such as Google Glass require fast access to powerful servers to achieve seamless interactivity with the real world; and online gaming clients need to communicate in real-time through centralised game services. A major obstacle to achieving this *hyper responsiveness* is the performance of the underlying network that interconnects mobile clients and services. Network effects cannot be anticipated, let alone controlled, due to the unpredictability of wide-area networks and the fact that users roam between different networks.

Over time, organisations have gone to great lengths to reduce access latency to backend services by moving them "closer" to end users. In 2010, Google spent $1.9 billion on a data centre in New York, despite real estate prices being amongst the highest in the world, to gain direct access to local and global networks [5]. Similarly, cloud service providers such as Amazon AWS have rolled out new infrastructure in edge locations. Proactive measures against high network latencies, however, are limited by the fact that network proximity in a mobile setting is unknown a priori.

To enable hyper-responsive mobile apps, Balan et al. [1] first proposed *cyber-foraging*, i.e. the use of remote resources to augment smartphone capabilities. This led to proposals such as Cloudlets [7], which treat smartphones as thin clients served by virtual device clones, and systems such as MAUI [4] and CloneCloud [2], which apply a more fine-grained app partitioning to reduce response times.

In general, the above approaches can only improve application responsiveness to the extent that computation delays dominate performance. It remains a challenge to control the impact of high *network latencies*, especially when users roam between wireless networks of different operators.

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We propose **NOMAD**, a **distributed edge cloud platform** that decouples services from fixed hosting locations. It enables services to migrate seamlessly between edge locations, thus adapting to changes in network conditions and user roaming on-the-fly. Its main features are:

1. Network profiling. Mobile clients continuously profile network latency to all service locations in their environment. The active service site periodically collects all profiling information and decides to migrate a service if it benefits clients collectively by minimising the maximum perceived latency.

2. Transparent service migration. NOMAD snapshots the state of the backend service without requiring application modifications [3]. A snapshot includes application memory page files and raw data images that capture IP addresses and routing tables.

3. Caching mechanism. To minimise service disruption during migration, NOMAD uses a caching approach in which migration occurs via the clients, and previous state snapshots are cached to avoid retransmitting unchanged backend state.

Demo: We demonstrate a NOMAD prototype over an emulated network using the CORE network emulator [6]. The demo shows how NOMAD can support *Cube 2: Sauerbraten*, a first-person shooter game with stringent low latency requirements. A major concern for this game is to provide fair performance amongst multiple clients. NOMAD improves the overall game experience by keeping the lag between clients low, despite changes in network conditions due to user roaming. Due to NOMAD's caching mechanism, the time to migrate a service is also kept low, i.e. in the order of seconds.

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