Adaptive Interest Modeling Enables Proactive Content Services at the Network Edge

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Abstract—We have successfully applied user modeling in a networking project. The goal of the project was to develop the network services to enable efficient and transparent distribution of content in mobile ad-hoc network (MANET) environments often deployed in emergency and tactical situations. How to get the relevant content to the right user quickly, in the midst of network disruptions and resource constraints, is a key research challenge. To address this problem, we have developed adaptive interest modeling (AIM) to capture user interests and information needs and build an interest model (IM) for each node. One key contribution of our approach is to anchor AIM at the content-based network layer, which allows all upper level mobile applications to benefit without modification. This adaptive IM can enable many user-aware features including content prefetching and IM sharing. We have developed a unique type of prefetching that is based on recognizing user situations. IM sharing is a novel and efficient way of automatically keeping users up to date with each other. This is especially useful in tactical scenarios where it is important to have a common operational picture among users. Our network emulation experiments show that IM-enabled prefetching significantly reduces response time while increasing data availability at the same time. When combined with IM sharing, additional sizable reduction in response time is achieved.

Keywords—user modeling; context awareness; mobile device; interest; MANET; network layer; content availability; prefetch; sharing

1 Introduction

As mobile computing technology rapidly advances and mobile devices become increasingly popular, more and more content is being generated by mobile devices such as mobile phones, tablets, and laptops. In addition, mobile devices can be rapidly

deployed as a mobile ad-hoc network (MANET) at the network edge where fixed infrastructure is minimal or non-existent. With a large number of content-producing nodes, the edge network not only serves as communication medium, but becomes a distributed data store with each node as a potential content producer and consumer [5]. This type of content-based edge networking plays an increasingly important role in both tactical and emergency response operations [2].

Content-based edge networking requires efficient network services for disseminating, managing, and securing the distributed content. These content services can all benefit from the understanding and modeling of individual node's interests and information needs. Modeling of user interests at the network layer becomes feasible with recent advances in content-based networking architectures, which provide a host-to-content abstraction in the form of publish/subscribe primitives. In the ICEMAN (Information Centric Mobile Ad-hoc Networking) architecture, for example, both the subscription interests and publication metadata are uniformly represented as attribute-value pairs [5]. The queries express the user's explicit interests while the content metadata indicates the user's implicit information needs.

2 AIM Approach

Figure 1 shows a high-level view of AIM's modeling approach under the ICEMAN architecture. User and network events are continuously monitored at the network level. The events include user queries, subscriptions, publications, and shared information. These events are then processed by the adaptation algorithm, which infers user's interests and information needs and produces an IM, which consists of relevant and time-sensitive information elements such as terms and ontological entities (depicted as colored dots in the diagram). An information element represents one dimension of a user's interest. Once built, the IM can enable powerful applications including content prefetching and IM sharing. Given that the IM represents the user's latest interests, it is natural to use it to anticipate warfighter's near-term information needs and automatically prefetch relevant content on the user's behalf. In tactical scenarios, IM can also be shared among users to help create a common operational picture (COP), which improves user's situational awareness (SA). Content prefetching and IM sharing complement each other and together they bring faster query response, higher content availability, and better SA.

The AIM adaptation algorithm used for modeling the user's interests is an extension of the Reinforcement and Aging Modeling Algorithm (RAMA), which was developed in our previous research programs and was demonstrated to be effective in a formative evaluation study conducted by NIST [1],[3,4]. The adaptation algorithm monitors subscription and publication events. It then applies reinforcement and time-based information decay to build an adaptive IM for each node based on these events.

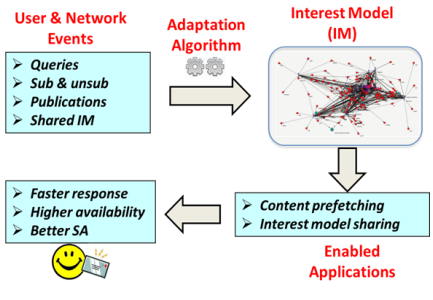

Figure 1. The AIM approach

3 Content Prefetching

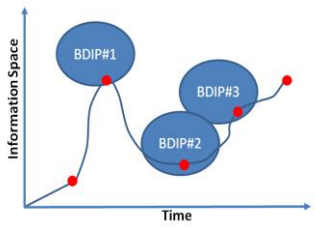

Figure 2. IM-enabled and profile-based prefetching

The adaptive IM can enable content prefetching in different ways. IM-enabled and profile-based prefetching (IPP) is a unique type of prefetching based on recognizing user tactical situations. The recognition is achieved by comparing IM and profiles that describe common operational situations such as battle drills, which are "a collective action, executed by a platoon or smaller element (http://usacac.army.mil/cac2/call/thesaurus/toc.asp ?id=4965)." A battle drill-derived information profile is referred to as a BDIP, which contains terms that describe the required information needs for a battle situation.

In IPP, we first manually create BDIPs (blue circles in the figure) for common military operations such as improvised explosive device (IED), cordon, and search (Figure 2). AIM then builds and continuously updates the IM (red dots) based on the user and network events. Whenever the current IM is updated, it is compared with the BDIPs to find the best match. As the IM continues to evolve over time, a matched profile may become dissimilar and a new profile may become more similar. This can happen when the situation on the ground changes. For example, cordon and search operations are interrupted by an IED explosion. In this case, the IM may initially match cordon and search profiles, but later switch to an IED profile. When a match is found, the information elements in the profile that are not covered by the IM will be used for prefetching. Content matching these elements is automatically fetched and cached when it becomes available and typically before it is requested by the user.

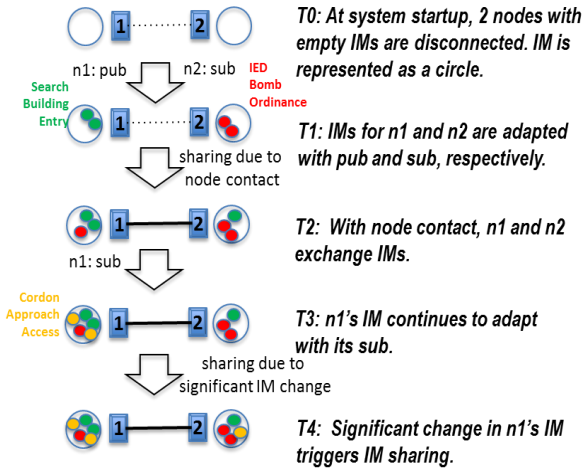

Figure 3. Scenario: IM sharing improves SA

4 IM Sharing

IM sharing is a mechanism for a node to automatically share its IM with other nodes on the network. There are two triggers for IM sharing: a) upon radio contact with a neighbor; and b) when the IM changes significantly. Once triggered, IM sharing is accomplished by sending a new data object encoded with IM elements to connected neighbors. Upon receiving neighbor's IM, the encoded information elements will be incorporated into the receiver's IM via the AIM adaptation algorithm.

IM sharing provides two benefits for the user. Firstly, it can work with AIM prefetching to impact the network performance. In particular, when IM is updated due

to receiving shared IMs from neighbors, IPP may be triggered to perform automatic prefetching. Another benefit is to help build a COP at the edge for better SA in a tactical situation. A notional scenario with two nodes shown in Figure 3 illustrates how AIM can improve SA.

5 Evaluation and Conclusion

We implemented AIM as well as the IM-enabled prefetching and IM sharing features in a content-based MANET prototype. We evaluated these features in a network emulation environment in two studies in a setup with 12 network nodes. Here we only present the results summary due to space limitation. IM-enabled prefetching significantly reduces response time (over 50%) while increasing data availability at the same time. When combined with IM sharing, additional sizable reduction in response time is achieved. Naturally there is a trade-off between these benefits and the associated cost in terms of increased bandwidth consumption.

In conclusion, we have developed the AIM capability for content-based mobile edge networking. It runs at the network layer in the ICEMAN prototype to enable proactive content services including prefetching and IM sharing. Of course, other applications of AIM would also be worthwhile to study in the future, such as the use of IM to influence ICEMAN's caching strategies (e.g., purging and replacement). There is also potential to make our approach more adaptive and focused so that the bandwidth overhead is reduced, e.g., avoid prefetching/IM sharing when the network is already over-utilized.

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