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A Mobile Cloud Computing System for Emergency Management

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ABSTRACT:

The mobility management system for mobile cloud computing, M²C², aims to select the best cloud and network for processing sensor data while responders are in an emergency area. Natural and manmade emergencies can cause tremendous economic, environmental, and, most importantly, human loss. Recent emergencies, such as the Indian Ocean tsunami, Hurricane Katrina, and the 9/11 terrorist attacks in New York City, caused significant loss of human lives. It is estimated that more than 280,000 lives were lost due to the 2004 Indian Ocean Tsunami.[1] A recent report argued that the use of an information and communications technology (ICT) infrastructure could be beneficial for evaluating and responding to emergency situations.[2]However, ICT's full potential in emergency management is yet to be realized. For example, we need robust ICT systems that provide situational awareness of the emergency area and offer improved decision support to manage emergencies efficiently

Introduction

The mobility management system for mobile cloud computing, M²C², aims to select the best cloud and network for processing sensor data while responders are in an emergency area. Natural and manmade emergencies can cause tremendous economic, environmental, and, most importantly, human loss. Recent emergencies, such as the Indian Ocean tsunami, Hurricane Katrina, and the 9/11 terrorist attacks in New York City, caused significant loss of human lives. It is estimated that more than 280,000 lives were lost due to the 2004 Indian Ocean Tsunami.[1] A recent report argued that the use of an information and communications technology (ICT) infrastructure could be beneficial for evaluating and responding to emergency situations.[2]However, ICT's full potential in emergency management is yet to be realized. For example, we need robust ICT systems that provide situational awareness of the emergency area and offer improved decision support to manage emergencies efficiently. Emergency management also requires safe evacuation of people from the danger zone; thurs, an emergency management system must also collect, pocess, analyze, and disseminate relevant, accurate, and timely information.[3–5]

Information about evacuees, responders, and the emergency area can be collected from various sources, including onsite or on-body sensors, wearable devices (such as Google Glass) worn by the responders, mobile nodes (such as smart phones), and cameras. This information can either be processed on responders' mobile nodes or offloaded to the remote facility for better decision making. However, three key issues need consideration. First, mobile nodes have limited processing, storage, and battery resources and might be unsuitable for processing the large amounts of data originating from sensors and cameras. Second, timeliness in

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emergency management is crucial, and data upload and download to and from remote sites might not be feasible. Therefore, the data originating from the emergency area should be processed near the source to minimize end-to-end latency. Finally, we expect the devices, sensors, and cameras to be with the responders, who might move between several access networks. These devices might experience handoffs, intermittent network connectivity, and limited bandwidth and coverage area.

Emergency management can benefit significantly from mobile cloud computing (MCC), which enables offloading of computation and storage from mobile devices to the nearest cloud, preferably at the first hop.[7] MCC can enable fast and secure access to relevant information required by the entities (such as responders) involved in an evacuation. Future wireless base stations or access points will likely have cloud functionality, bringing the cloud to the edge of the network, and significantly reducing end-to-end latency and increasing device battery lifetime.[7,8] But to successfully integrate MCC into emergency management, we must address mobile and cloud computing challenges such as mobility management, handoffs, intermittent network connectivity, network latency, limited network bandwidth, network congestion, limited coverage area, and battery lifetime.[6,9] MCC also needs to handle challenges associated with cloud resource management for efficient application provisioning while responders are on the move. For example, cloud quality-of-service (QoS) parameters (CPU, RAM, and disk I/O) can vary stochastically depending on user demands and workloads.[10]

Our mobility management system for mobile cloud computing, M^2C^2, uses multi-homing to ensure seamless network handoffs (with low latency and packet loss) when the mobile node roams in an emergency area. It also incorporates cloud and network probing; and metrics for cloud and network selection based on application requirements and network and cloud load. To the best of our knowledge, M^2C^2 is the first MCC system to support cloud and network-aware mobility management while responders are roaming in an emergency area.

Mobile Cloud Computing for Emergency Evacuation

Consider the scenario, where a group of responders are deployed in an emergency area to evacuate people. The evacuation area is divided into several zones, with each zone having an emergency response vehicle (ERV). Each ERV provides local cloud functionality accessible via Wi-Fi, 3G, and satellite networks. The responders are equipped with mobile nodes (for example, smartphones), wearable devices (for example, Google Glass), and sensors (for example, accelerometers; GPS; temperature, and humidity sensors; and so on), which connect to local clouds for lowlatency

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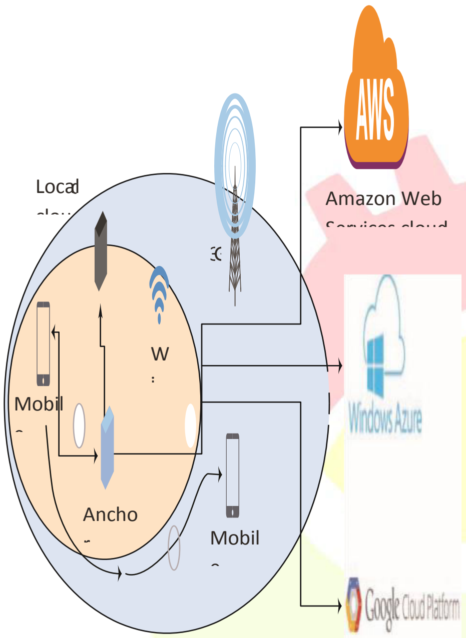

data processing, storage and access. The local cloud in each zone might also connect to the command station via 3G or a satellite link for holistic situational awareness of the emergency area. As a failover mechanism, the local cloud can also connect to public clouds for redundant data processing and storage.

The data originating from all the responders in a particular zone—that is, from their sensors or applications running on the mobile node—is transmitted via Wi-Fi or 3G networks to local clouds for processing, storage, and analysis. If the Wi-Fi network doesn't provide sufficient QoS because of signal fading or network congestion, the responder's mobile node can handoff to a 3G or satellite network (or vice versa) for data transmission. However, a handoff can cause temporary network disconnection, leading to intermittent cloud connectivity for data processing and access. In addition, the nearest cloud might be susceptible to QoS degradation owing to large amounts of data being transferred and processed through it. Clouds must therefore be able to offload processing or storage to another local or public cloud. In regard to this, M^2C^2 provides fast and reliable data processing and access via the best clouds and the best available access networks.

A Mobility Management System for Emergency Evacuation

Figure shows M^2C^2's high-level architecture, which includes Multihomed Mobile IP (M-MIP),[11] a mobility management protocol, to support efficient handoffs between several access networks. Using M-MIP, a mobile node connects to several access networks simultaneously and probes them before initiating the handoff process (between these access networks). In particular, mobile nodes perform network discovery, network configuration, and network registration for all available networks in advance, considerably reducing the number of steps during the handoff process, and resulting in low-latency handoffs with minimal packet losses.

M^2C^2 also incorporates several network and cloud entities to enable cloud and network probing and selection. These entities include local and public clouds, such as Amazon Elastic Compute Cloud (EC2), Microsoft Azure, and Google Cloud Platform, home agent, cloud probing service (CPS), cloud ranking service (CRS), mobile node, Wi-Fi and 3G networks,

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and an anchor point. In M^2C^2, an anchor point can perform several roles. It can act as the home agent and assist a mobile node by providing it with network probing and handoff management functionalities. The anchor point can also run the CPS to probe local and public clouds, as well as the CRS to select the best cloud for applications to offload computation and storage. The mobile node periodically tracks both clouds and networks via these M^2C^2 entities (anchor point, CPS, and CRS) so applications can determine the best cloud and network while responders roam in heterogeneous access networks (HANs), covering an emergency area.

Network Probing and Selection Mechanism

To select the best available network interface i, where i ∈I, the mobile node performs passive network path probing to compute the relative network load (RNL_i) metric for each i.[11] In particular, a mobile node probes all the available networks *I* simultaneously by periodically sending binding update messages to the home agent and by receiving the corresponding binding acknowledgment messages from the home agent. The amount of time between the mobile node sending a binding up data message to the home agent and receiving the corresponding binding acknowledgment message from the home agent is the *roundtrip time* (RTT). M2C2uses the RTT values to compute the RNL metric for determining the load on access networks. We compute the RNL metric as follows:

bile node probes all the available networks I simultaneously by periodically sending binding update messages to the home agent and by receiving the corresponding binding acknowledgment messages from the home agent (see Figure). The amount of time between the mobile node sending a binding update message to the home agent and receiving the corresponding binding acknowledgment message from the home agent is the roundtrip time (RTT). M^2C^2 uses the RTT values to compute the RNL metric for determining the load on access networks.

We compute the RNL metric as follows where S_n is the sending time for the binding update packet from the mobile node to the home agent where n∈N; R_n is the time the binding acknowledgment packet is received at the mobile node from the home agent; h is the history window for calculating the weighted average, where h = 5 is considered to be an optimal value[11]; and c represents the weight of the RTT jitter value compared to the RTT value. For instance, the value c = 5 means that the RTT jitter value contributes five times more than the RTT value. Finally, we initialize the variables Z, D, and J as $Z_0 = RTT_0$, $D_0 = 0$, and $J_0 = D_1$. The network i with a lowest RNL value [min(RNL_i)] is the target network for handoff. Cloud Probing and Selection Mechanism M^2C^2 mechanisms for cloud probing and cloud ranking support QoS-aware cloud selection. The anchor point or any other dedicated network element on a particular access network can run the CPS (see Figure 2), which tracks the QoS statistics (CPU, memory, and

$$RNL = Z_n + cJ_n \quad (1)$$

$$= RTTn + \frac{1}{h} \quad \frac{h-1}{} Zn-1h \quad h \quad (2)$$

$$RTT_n = R_n - S_n \quad (3)$$

$$D_n = RTT_n - RTT_{n-1} \quad (4)$$

1 h−1

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I/O) of both public and local clouds by probing them regularly using RESTful APIs. The anchor point or any other dedicated entity in the network can also run the CRS, which retrieves the QoS stats from CPS (using a RESTFul API) and computes the rank for each cloud $k \in K$ (where K represents all available clouds) based on criteria such as application type, CPU utilization, memory utilization, and disk I/O. Using a RESTful API, the mobile node can then retrieve the best cloud k based on the computed rank (R_k) for a particular application. The mobile node will then use the kth cloud for task processing and storage.The URL of the RESTful API (for retrieving the best cloud from CRS) is http://<CRS IP addr.></ cloudrankservice>. The tag <CRS IP addr.> represents the IP address of the CRS, and the tag </cloudrankservice> is the Web resource where the CRS is running. The mobile node makes a GET call to this URL and retrieves the best cloud as an HTTP response. Also, a GET call to http://<CRS IP addr.></cloudrankservice><appl. type> retrieves the best cloud k based on the supplied application type where the tag <appl. type> represents the different types of applications—for example, a critical medical response application.CRS selects the best cloud k by computing the rank of each cloud $R_k \forall K$ using the simple additive weighting (SAW) scheme (Equation 6), a multicriteria decision-making method (MCDM).[12] We rank the clouds using the following formula:

$$R_k = w_l(QoS_j) + (1 - w_l)(Cost_j), (6)$$

where $j \in J$ represents the jth QoS and cost parameter for cloud $k \in K$;R_k represents the rank of the kth cloud; w_l represents the weights associated with each parameter QoS_j and $Cost_j$ for each application $a \in A$;and $\sum_{l=0}^{N} w_l$ =1. The parameter $Cost_j$ can be a monetary or probing cost related to a cloud service. The parameter QoS_j represents QoS parameters, such as CPU utilization, network throughput, and end-to-end latency. Some QoS parameters, such as throughput need to be maximized, whereas others, such as cost, need to be minimized. We select the cloud with the highest R_k (computed using Equation 6) as the best cloud.

As the mobile node starts roaming in the HANs, it constantly computes the RNL_i metric (using Equations 1 through 5) for all networks I. Using the RNL_i values, the mobile node makes handoffs with low latency and packet loss that don't adversely affect the applications running on the mobile node. At the same time, the mobile node retrieves the best cloud k from the anchor point and offloads the computation/storage based on the selected cloud k.

Results

To validate our proposed system, we developed an activity recognition application service that uses various sensors (accelerometers, temperature sensors, GPS, and so on) to determine responders' activities in an emergency evacuation. The use of activity recognition applications in areas such as cognitive assistance, emergency healthcare, and emergency management will likely increase significantly in the near future. In these areas, an activity recognition application might require a

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large amount of sensor data collection, fast activity recognition, and timely delivery of results to the user (responders and command center). However, performing all these steps on a responder's mobile node could reduce battery lifetime and/or increase latency.[8,13,14] Therefore, we envision the system performing activity recognition on clouds instead of mobile nodes to maximize battery lifetime while providing low-latency computation and access. The major challenges posed by activity recognition applications running on clouds are

- efficient data collection from sensors;
- timely sensor data delivery to cloud-based activity recognition applications;
- timely activity recognition using activity recognition algorithms; and
- timely results delivery to the user.

We focus on the latter three tasks. For timely sensor data and results delivery, the mobile node must select the best network i that provides high throughput and low packet loss and delay. For timely activity recognition, the mobile node must select the best cloud k that determines the responder's activity in a timely manner.

Our results clearly validate that M^2C^2 can efficiently support time-critical applications in emergency management scenarios while responders are on the move. M^2C^2 successfully tracked the QoS parameters of all clouds K and all wireless networks I to determine the best cloud k and network i for activity recognition. e're in the process of integrating speech and location recognition and face detection application to M^2C^2, which we believe might be beneficial for evacuating people in an emergency area. The proposed system can also easily be extended to include other applications that can be valuable in emergency evacuation scenarios, such as optical character recognition and augmented reality.

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