Vehicular Cloud Computing

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***Abstract*—Mobile Cloud Computing is a new field of research that aims to study mobile agents (people, vehicles, robots) as they interact and collaborate to sense the environment, process the data, propagate the results and more generally share resources. Mobile agents collectively operate as Mobile Clouds that enable environment modeling, content discovery, data collection and dissemination and other mobile applications in a way not possible, or not efficient, with conventional Internet Cloud models and mobile computing approaches. In this paper, we discuss design principles and research issues in mobile cloud computing. We then focus on the Mobile Vehicular Cloud and review cloud applications ranging from urban sensing to intelligent transportation.**

I. Introduction

Mobile Cloud Computing (MCC) is an emerging paradigm where individual mobile devices can be both cloud users and service providers. Mobile phones are overtaking PCs as the most popular Web access method. By the end of this decade, a significant fraction of web access (from mobile as well as fixed devices) will be to mobile services and resources. This is because many of our queries will be about the world surrounding us, and mobile agents (people and vehicles) are the best probes of this environment. Moreover, the data of interest may be scattered across many mobile observers, and will require in loco data aggregation and query resolution using software specialized for the local context. These mobile agents effectively form ***Mobile Clouds*** that offload the Internet Clouds from tasks that the latter cannot perform in a timely or efficient manner. For instance, a driver queries the Mobile Vehicular Cloud to find the cause of a sudden traffic jam (say, a minor accident in the next block). This type of information is created, maintained and propagated within the Mobile Cloud. It would be too costly to upload every traffic minutia to the Internet, and too time consuming to search the global Internet traffic cloud for such results. The increasing storage and processing capacity of the mobiles on one hand, and the scarcity of urban spectrum on the other make it more effective to communicate and keep the locally relevant content on the mobiles instead of uploading it to the Internet Cloud. The benefits of using the Mobile Cloud instead of the Internet Cloud are reduced communication delay, reduced spectrum costs and amply expanded range of applications. In the new scenario, the mobiles upload to the Internet Cloud only the content of global, long lasting value and delegate to it only those tasks that are too complex or too energy consuming to process in the Mobile Cloud.

II. Mobile Cloud Scenarios and Research Issues

Mobile Cloud Computing research is aimed at understanding how these clouds form, possibly exploiting existing social ties, and what are new social networks they create. What new privacy/security issues they pose. How they leverage the Internet Cloud for complex, energy consuming tasks. We envision three representative scenarios as follows.

Mobile Vehicular Cloud. In the Vehicle Cloud, the leading applications are safe driving, urban sensing, content distribution, mobile advertising and intelligent transportation. For example, vehicles pick up information via sensors (e.g., congestion, pavement conditions, surrounding cars, environment video clips, advertisements, etc.). They organize, exchange and keep the data local, since local relevance and sheer volume of this data make Internet upload unattractive. Other vehicles or Internet users can search for the data in the Vehicle Cloud with proper indexing and scoping. There will also be significant computing on this cloud. For instance, computation of the full urban congestion picture; computation of the urban pollution map; collaborative reconstruction of pictures/video in accident or crime scenes; coordinated identification of possible terrorist threats; etc.

Mobile Personal Cloud of smart phones and tablets that support mobile social computing, mobile healthcare, urban sensing and entertainment. Imagine for example the capturing of different views at a concert or sports event and sharing such views with bystanders. The Personal Cloud differs from the vehicular one because it offers a different and more diverse set of applications. It also offers stronger social networking implications among its members than the Vehicle Cloud. Drivers are too busy to go from A to B to socialize. On the negative side, it has major battery power limitations. The tradeoff between Personal Cloud storage and processing versus Internet Cloud uploading must be carefully evaluated application by application. Power and data hungry applications definitely benefit from Internet offloading. And so do the applications that rely on Internet Social Networks such as Facebook, Four Squares and Twitter. On the other hand, privacy considerations will drive the users to keep sensitive data on their mobile devices.

Mission Oriented Mobile Clouds consist of both humans and robots for goal oriented activities (e.g., terrain exploration, disaster recovery, surveillance, environment monitoring, crowd sourcing, etc.). While vehicular and personal clouds are opportunistic clouds brought together mainly by coincidence of

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commuting needs or by geographical proximity criteria, Mobile Mission Clouds are preplanned. For example, an enterprise mobile cloud, or; a team of first responders exploring on foot or by vehicle a disaster area, or; a party of volunteers equipped with sensors that roam the streets spontaneously monitoring and recording (on their devices) the environment exposure (e.g., urban pollutants, UV radiation, street noise, etc.). Diagnostic preprocessing of the data may be distributed across the mobile cloud before (or in lieu of) access to a Health Services Cloud for reasons of efficiency as well as privacy and security. There are significant differences in privacy (mission agents know each other), and possibly in communications costs as mission members may be geographically separated.

III. Cloud Research Challenges

New research directions are required to efficiently deploy and manage a Mobile Cloud. In particular:

Privacy and security protection: A major incentive for mobile cloud participants is to protect the data and allow users to decide what information could be exposed and what information should be kept private. Moreover, functions, data, and trust validations of mobile applications can be delegated to MCC, if mobile devices and mobile users become temporarily disconnected. MCC also provides protection from devices that have been penetrated by the adversary, or exhibit uncontrolled, disruptive behavior.

Sensor filtering and aggregation: One major advantage (and challenge) of MCC applications is to efficiently aggregate sensing, filtering and processing capabilities across the Mobile Cloud as a function of the application and the context.

Content-based, secure networking: This is a fundamental paradigm in the Mobile Cloud, where new content is continuously added, signed and replicated across agents, without a central directory. In the lack of central authority, distribution of (and access to) content must be controlled via trust management that relies on the intrinsic mobile cloud social structure. Associated with content search is the caching of data at intermediate nodes following the search. The cached data can efficiently satisfy future searches for the same content, and is the foundation for efficient content based routing.

In the rest of the paper, we direct our attention to the Vehicular Cloud and its applications.

IV. The Vehicular Cloud

Collectively, vehicles represent a phenomenal computing resource, in terms of storage and processing. Moreover, they are well connected by a capillary Vehicle-to-Vehicle (V2V) communications network. However, the unique power of the Vehicle Computing Cloud does not rest on the computing resources (like for the Internet Clouds) but on the sensors they carry. In fact, vehicles are ideal observation platforms for the environment and can see and memorize a large degree of detail (well beyond the fixed cameras installed on side road structures). Moreover, the information they store has local relevance. For example, it is very likely that a driver entering the city restaurant district can get restaurant recommendations directly and with more content from vehicles in the neighborhood than from the web. These two principles unlimited ability to collect sensor information and local relevance of the information represent the prime advantage of the Vehicle Cloud over the Internet Cloud. By keeping the information on the vehicle, we save the cost of uploading the information to the web and the associated storage. Moreover, we save the download cost and time, assuming that we implement an efficient search method for content in the Vehicle Cloud. Locality of interest and timeliness are particularly true for urban sensing and traffic management applications. In the sequel, we examine these two applications in more detail.

A. Urban Surveillance service in the Vehicular Cloud

Environment monitoring and surveillance using video cameras and sensors are increasingly important functions in any urban center. Vehicles are ideally suited for surveillance (and more generally, environment sensing) complementing fixed video cameras and sensors installed in the infrastructure (light poles, roof tops, traffic lights, etc.). Vehicle surveillance may be used to prevent possible attacks. For example, a tip was received, that a terrorist group with given vehicles and/or driver profiles will be roaming a certain area of the city planning an attack to some critical infrastructures. To prevent such an attack, the city may deputize selected vehicles in the cloud to detect and report suspected activities. Video surveillance is important also for forensic investigation, AFTER the incident has occurred. For example, it can be used to investigate a traffic accident, or to reconstruct the approach path of a truck bomber after the attack. In the forensic case, video is stored on board of the vehicle, waiting to be “harvested in the rare event that it is needed (because and accident really occurred, for example). Uploading to Internet servers is not an option because the sensed data is massive (e.g., all the license plates read by all the vehicles). Keeping the data on board along with some form of epidemic diffusion to facilitate its search is the preferred strategy.

For the purpose of urban surveillance, we have designed MobEyes, a novel mobile sensor middleware that supports proactive urban monitoring applications [1], [4]. MobEyes exploits wireless-enabled vehicles equipped with video cameras and a variety of sensors to perform event sensing, processing and classification of sensed data, and inter-vehicle ad hoc message routing. Since it is impractical to directly upload the sheer amount of sensed data to the Internet, MobEyes keeps sensed data in mobile node storage. From the sensed data, on board processors extract features of interest, e.g., license plates, and periodically generate metadata appending to sensor data critical context information such as timestamps and position coordinates. These summaries are disseminated periodically in the Cloud. Mobile agents, e.g., police patrolling cars, when alerted, move and opportunistically harvest summaries from neighbor vehicles. Alternatively, the data vehicle cloud can be searched from the Internet using MobEyes custom designed protocols. Typical queries include: which vehicles were in a given place at a given time; which route did a certain vehicle

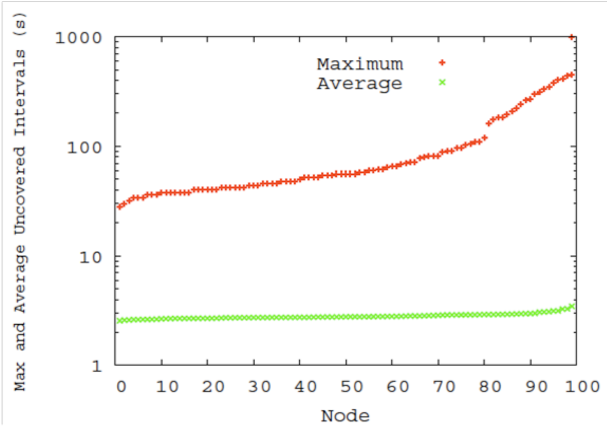

Fig. 1. Maximum uncovered intervals per node.

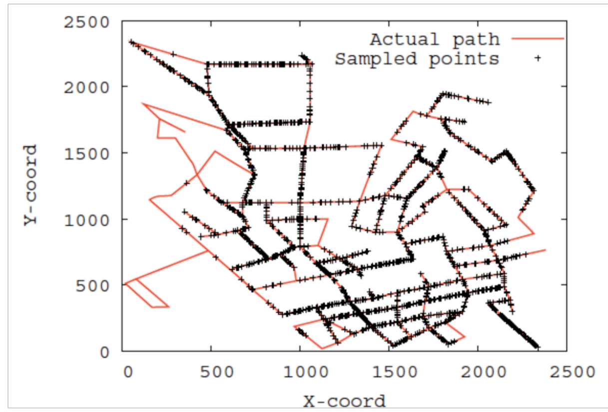

Fig. 2. Actual node trajectory vs. harvested sampled points.

take; and which vehicle holds the data of interest.

To test MobEyes effectiveness, we have simulated a vehicle tracking application where the agent reconstructs vehicle trajectories exploiting the collected summaries. The application is related to the aforementioned tracking of suspect vehicles with terrorist intentions, except in this case we track all vehicles in order to assess MobEyes feasibility and scalability for this type of application. This is indeed a challenging application, since it requires our system (1) to monitor a large number of targets, i.e., all participant vehicles, (2) to periodically generate fresh summaries, and (3) to deliver to the agent the generated information upon request. As the agent retrieves a record, it extracts node license plate, time and location. If there is a match, the agent puts it on the map. By aggregating data from different summaries, a fairy accurate trajectory is reconstructed.

To determine the effectiveness of the method, we have considered an urban 1km x 1km square grid scenario, with 100 vehicles randomly roaming in it. We have evaluated the average and maximum uncovered interval per vehicle. The longest untracked interval represents the situations when a node moves in a low vehicle density zone. We associate the average and maximum uncovered intervals to each simulated node, and present the results in Fig. 1 (note the logarithmic scale on the Y-axis).

Every point in the figure represents the value of the parameter for a different node. We sorted nodes on the X-axis so that they are reported with increasing values of uncovered interval. Results are collected during a 6000s simulation experiment. The plot shows that in most cases the average uncovered interval fluctuates between [2.7s∼3.5s]. The maximum uncovered interval shows that even in the worst cases the agent has at least one sample every 200s for more than 90% of the participants. A more immediate visualization of the inaccuracy is given in Fig. 2. This figure shows the "real" trajectory, for the vehicle with a maximum uncovered interval equal to 200s (the unbroken line), and the sample points the agent collected. The uncovered interval corresponds to the portion of the route in the periphery of the area of interest, where a few vehicles are roaming.

B. Vehicular Traffic Management

Surveillance and route tracking is an example of application totally contained in the Vehicular Cloud (the Cloud stores the data and computes the trace). The next application we examine is vehicular traffic management. Work on vehicular traffic management and route optimization was begun back in the 60's, using road traffic models validated by measurements and mathematical programming techniques. However, the results remained in the academic domain and found little opportunity for implementation, mainly because until recently it was extremely difficult to "measure the vehicular traffic" in real time, and to "inform vehicles of the new routes". To overcome this problem, the approach taken by the Department of Transportation in the last decade was to measure the traffic by instrumenting the highways with sensors under the pavements and video cameras. This is a costly solution, which moreover detects the road segment traffic loads but cannot determine the traffic pattern (source and destination of the traffic). Secondly, the information about the "best route" was conveyed to drivers with billboards, radio announcement and, more recently, the Internet. Unfortunately, sending the same instruction to all the vehicles had the effect of creating "route flapping" problems and route instabilities. Everybody rushes to the newly announced route.

Recently, the introduction of on board navigators has changed all that. The Navigator Service Agency can learn instantaneous traffic flows and patterns from the Mobile Vehicle Cloud, and can deliver differentiated route instructions to vehicles thus avoiding route flapping. In the envisioned "Mobile Cloud enabled" traffic management, on board vehicle navigators periodically send time, GPS coordinates and final destination to a Navigation Server in the Internet. The Server estimates road segment loads and delays, constructs the traffic load map as well as the traffic pattern matrix. It then computes optimal incremental routes and returns such routes to vehicles upon request. An important benefit of the individual interaction between Navigator Server and on board navigator (as opposed to traffic billboard announcements) is the fact that the former allows to balance the load among multiple route options. Moreover, the on board navigator may choose, within some limits, between different route recommendations depending on the driver profile (aggressive or conservative driver) and type of vehicle (say, combustion or electric engine). Simulation results confirm the convergence to the optimal, minimum delay route solution at quasi-steady state [5]. This application is a good example of synergy between Vehicular Cloud and Internet cloud. In particular, the sensing of segment traffic congestion is done in the Vehicle Cloud (by means of reporting time and GPS position successive snapshots), as well as the route "actuation", through instructions received by the on board navigators from the Navigator Server. The Navigator Server, implemented in the Internet Cloud, does the rest. Namely, it computes the traffic pattern, from the destination ID carried by each on board navigator message. It computes optimal incremental routes and dispatches such routes to the on board navigators.

An interesting result from the study reported in [5] is the fact that even a small percentage of participating vehicles in the cloud can lead to significant delay improvements. For example, 10% penetration gives good improvements; 40% penetration practically gives the optimal solution. This property is valid also for other mobile cloud applications, like surveillance. There are, however, applications, like collision avoidance, that require full participation.

The above mentioned traffic management application lends itself to many possible extensions. For example, vehicles can exchange traffic information among each other to learn about problems within a few blocks and react accordingly. The knowledge of a malfunctioning traffic light, or a double parked truck can be very useful to make rapid detour decisions, more efficiently than waiting for the Navigator Server to learn about them and reflect them in its route instructions. There have been proposals for completely distributed traffic management [6], [7]. However, such schemes lack the ability to scale to large geographical areas. Moreover, they cannot exercise input traffic control. In fact, the coordinated control of the incoming traffic into an area (via traffic lights and possibly green waves) and to a freeway (via access ramp lights) is best done by a centralized controller. In the future, we can expect that traffic management will be the result of the interaction between Internet Cloud, Mobile Cloud and also Edge Cloud computing, the latter being done by the collection of servers at the edge of the network (including intelligent traffic lights and access points).

V. Conclusion

Vehicles represent an increasingly important source of computing and sensing resources for drivers as well as for urban communities. These resources can be harnessed by defining a mobile vehicular platform where several utilities can be created and shared among all vehicles on the road. The Mobile Vehicle Cloud has different but complementary functionalities with respect to the Internet Cloud. Target Vehicle Cloud applications bring together the environment sensing and the correlation between environment properties and outcomes that impact the drivers and the community, such as safe navigation, efficient traffic management, locally relevant information and entertainment.

In this paper, we have outlined two applications, urban sensing and efficient traffic management. We have identified the interplay between the Mobile Cloud and the Internet Cloud. We have also identified the role of V2V communications for the propagation of data to facilitate its search (in urban sensing) and for the support of distributed processing (in local route optimization). There are still several areas that must be explored, including: Data indexing and context based routing (to information of interest) [3], [8]; secure and privacy aware sharing of the data; storage and distribution of location relevant multimedia content generates by vehicles; exploitation of the "edge resources" in the urban grid, such that Access Points, traffic lights, ramp access controls [2], and; interaction of the Vehicular Cloud with the Personal Cloud of pedestrians in a city.

References

[1] P. Bellavista and E. Magistretti and U. Lee and M. Gerla, Standard Integration of Sensing and Opportunistic Diffusion for Urban Monitoring in Vehicular Sensor Networks: the MobEyes Architecture, IEEE ISIE, Vigo, Spain, 2007.

[2] M. Cesana and L. Fratta and M. Gerla and E. Giordano and G. Pau, C-VET the UCLA Campus Vehicular Testbed: Integration of VANET and Mesh Networks. European Wireless Conference, Lucca, Italy, 2010.

[3] V. Jacobson and D. Smetters and J. Thornton and M. Plass and N. Briggs and R. Braynard, Networking named content. ACM International Conference on Emerging Networking Experiments and Technologies (CoNEXT), Rome, Italy, 2009.

[4] I. Leontiadis and C. Mascolo, GeOpps: Geographical Opportunistic Routing for Vehicular Networks. World of Wireless, IEEE International Symposium on Mobile and Multimedia Networks (WoWMoM), 1-6, 2007.

[5] W. Kim and M. Gerla, NAVOPT: Navigator Assisted Vehicular route OPTimizer, IMIS'07, Seoul, S.Korea, June 2011

[6] V. Verroios and et al., Adaptive Navigation of Vehicles in Congested Road Networks, ICPS08, July 610, 2008, Sorrento, Italy, 2008.

[7] I. Leontiadis and et al., On the Effectiveness of an Opportunistic Traffic Management System for Vehicular Networks. IEEE Trans on Intelligent Transport Systems, Dec., 2011.

[8] S. Y. Oh and D. Lau and M. Gerla, Content Centric Networking in Tactical and Emergency MANETs. Wireless Days Conference, Venice, Italy, 2010.