Future Radio Access Networks Empowering Mobile Cloud Computing

Niko Kortström
Department of Computer Science
University of Helsinki
Finland
Email: niko.kortstrom@cs.helsinki.fi

***Abstract*—The abstract goes here.**

I. Introduction

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II. Mobile Cloud Computing

Mobile devices lack the computational power residing in personal computers. According to Satyanarayanan et al. this will always be the case because improving size, weight and battery life are higher priorities in designing them[5]. Of course while a design focus, battery life is still an issue when using mobile devices. There are also many other issues like problems with connectivity. Most applications can still be ported to run on mobile devices. Many of them are simple enough that the lack of resources is not an issue at all. Sometimes it can also be a good solution to limit the usability of an application to better fit it into its new environment. This can mean offering only some qualities of the desktop app. This kind of applications can be called companion apps. For example a huge multiplayer games companion app can simply offer a connection to the in-game chat or your characters inventory.

A hot topic called internet of things can benefit a lot from mobile cloud computing. When computational capacity is embedded into things not originally build for it, their resources are most likely close to non-existent. Using them as mere thin clients, providing inputs to applications running on the cloud is a good option until computational resources of these things evolves.

There are numerous problems that can't be solved solely on the limited resources of modern mobile devices. Some of these problems are image processing, natural language processing and multimedia search[1]. This is where mobile cloud computing comes into play. Using a much more powerful device or collection of devices, in other words a cloud, to carry out the brunt of computing solves this issue. In this situation, a mobile device could possibly be used just as a mean to display results of computation. There are several types of clouds that mobile devices can make use of.

1) Remote Cloud: This type of mobile cloud computing is mostly similar with traditional cloud computing. A user offloads some computations to a powerful remote cloud. The difference is that in this case the user interacts with the cloud via a mobile device instead of, for example a laptop or a desktop computer. Everyday services that make use of the remote cloud include some of the most widely used applications and web sites in the world, such as Facebook, Google search and Outlook.

2) Cloudlets: Cloudlets form a far less known type of mobile cloud computing. Compared to remote clouds, cloudlets can be seen as less powerful but more closely located clouds. Whereas remote clouds can be seen as huge clusters or warehouses full of computational power, cloudlet can be just a single laptop moving with the user or a desktop computer situated at a public location.

3) Cloud of Mobile Devices: Mobile devices can also be used to form clouds amongst themselves. For this to be possible, users must be willing to submit their mobile device's computational resources to be used by someone else. Another possibility is that multiple users are interested in the result of same computational task. In this case mobile devices will divide the task into smaller pieces and distribute it between the interested mobile devices. The computational capacity of mobile devices is increasing rapidly. Much of this capacity is often not being used. Having a way to harness this unused power could be a great benefit to both, the users offering and making use of it.

Main benefit of the more closely located clouds is not having to use long range connections. There can be many different reasons that it just isn't a valid option at the time to make use of remote data centers. It might be that it is too battery draining, pricey or time consuming to transmit over long ranges. There are also cases that long range connectivity isn't available as depicted in the disaster scenario of Wang et al.[2].

Bringing cloud computing closer to the user has been envisioned to happen via public cloudlets located as densely as Wi-Fi access points in todays world[5]. This would require numerous different parties to want to establish cloudlets, meaning that they need to gain some sort of benefit out of this. Wi-Fi access points are often deployed in public places to attract customers and offer them something to do while waiting for example. Similar to this case, if applications making use of cloudlets are interesting enough, people could seek out vicinity of cloudslets. Obviously to gain financial benefits, cloudlet owners could also sell their customers' personal information to third parties or owners of different facilities could allow third parties to set up their own cloudlets a fee.

Probably the most well known peer-to-peer systems are BitTorrent applications used to distribute entertainment. An application making use of a cloud of mobile devices can also be seen as a kind of peer-to-peer system. BitTorrent systems often encourage users to upload their already downloaded files to other users. Offering them higher download data rates in return is one widely used incentive. An example of a possible incentive[3] in case of mobile computation distribution is for service providers to offer discounts for users who distribute computation in cases of congested network bandwidth.

There are also reasons why users should offload some of their computation when possible, even if they aren't paid for it. Usually offloading computation directly helps with an inherent limiting factor of mobility: battery life. This is quite clear as heavy computation consumes battery fast, minimal computation consumes it a lot slower. However, the issue isn't quite as simple since we also have to account for the amount of battery used by network connection. Connections can limit the possibilities of mobile devices cloud usage if not available but they can also consume a lot of power when used. We must make sure that energy cost of offloading computation isn't too high compared to the energy save.

Trade-offs of mobile cloud computing must be considered. For this purpose there are a lot of different models[1] to closely look into the cost-benefit relationship of mobile cloud computing. These models can possibly be used by humans to deside if it would be useful to offload some of the computation of a specific application. Since benefit of offloading computation is often environment dependant, it is also useful for the application itself to be able to determine whether and how to offload.

When discussing moving computation from one entity to another we obviously need to have some kind of method to transfer the data efficiently. Three different methods are considered suitable for this purpose[1]: client-server communication, virtualization and mobile agent. Client-server communication requires the cloud to have some kind of pre-installed interface available for the client to call. When using virtualization, an image of the current memory state of the client is transferred as an image to the server where its execution is resumed. Mobile agent approach includes splitting up the program code from suitable points and sending it ahead to the cloud to be executed. These points can be chosen by the programmer beforehand or the application can for example use an analyzer to find them[2].

Distributing computing to multiple mobile devices also offers other possibilities. One such is also distributing the applications input or sensing capabilities. Distributing a problem to be solved with the help of multiple users is called crowdsourcing. Users can collectively form larger data sets to be processed. Larger data sets often mean more accurate and reliable results, no matter what data we are talking about. There are many[4] possible applications that could benefit greatly from such an approach.

Modern mobile devices are able to collect enormous amounts of information about our habits, schedules and interests etc. We also use mobile devices to access vital services such as banking. Making applications residing in mobile devices interact with the cloud, directly causes additional security threats to both data about our everyday life and different kinds of personal information. Making sure that no data is disclosed to unwanted parties is a requirement that should absolutely be met before making use of cloud in an application. Additional aspect to consider is that in traditional cloud computing, cloud is usually owned and maintained by some well knows corporation that is considered quite trustworthy. In cases of cloudlets and mobile clouds, targets of offloading cannot be always known beforehand. This makes ensuring security and privacy even more difficult.

All these different kinds of clouds, or more precisely combining them, also means rethinking the architecture of applications that we develop. Not only applications might have to be able to choose whether to offload computing, they may also need to pick the best destination for offloading. Having different layers of cloud is a new factor to keep in mind. Programmers need to be able to make applications smart enough for them to get the maximal benefit. This isn't simple as there are many things to compare, like available resources, data rates and network congestion.

Cloudlet and mobile device solutions also contain additional challenges due to mobile devices moving constantly along with their users. Some of the great benefits of these approaches are saving energy and radio access bandwidth by using bluetooth for example. Transmitting the results of offloaded computation while it is still possible, before the device that issued the task moves out of range is essential. How to know make sure this happens is a great challenge for application designers[3]. Losing all the results of offloaded computation right before it's finished can result in much worse processing time, compared to not distributing computing at all. One way to solve this problem is location based offloading[4]. Of course querying users' location adds to the computational needs so it would have to be used sparingly. This is again one problem that could use a powerful artificial intelligence to be solved.

III. Upcoming Radio Access Networks

Fifth generation mobile communication technology is to be released for consumer use in 2020. There are numerous important and really challenging qualities that are required to be met before the next generation cellular communications techology can be released. 5g standards are yet to be created. Still, many expectations have already been visioned.

Gohil et al. [6] offer their views on what will and should be included in next generation radio access networks. This paper seems like an early review of peoples opinions rather than evidence based research as to what 5g will really be but it offers a good glance at the subject. Some of the technical qualities highlighted in the paper include seamless cooperation of different radio access technologies, combining cellular and ip connectivity and new protocol stack architecture which all sound interesting and powerful concepts. They also list some practical features associated with 5g. Advanced billing interfaces, large data rates, better consistency and reduced latency are some of these.

Andrews et al. [7] offer similar but more recent and in my opinion much more accurate description of the fifth generation of cellular networking. Requirements set for 5g are described pretty accurately in the paper. They include areas of data rate, latency and energy and cost efficiency. It is also stated that while great challenged to be achieved, all of the goals don't necessarily have to work in practise at the same time. Example is given that streaming high-definition video needs the high data rates but can do with a higher latency. Then again the situation is reversed for driverless cars, low latency is crucial but data rates can be lower. Coming of internet of things also suggests a need for supporting huge amounts of connections from really heterogenous device base. Low rate device-to-device connections functioning side by side with high rate mobile user connections require a new approach to mobile core management and control functions.

Three clear requirements are set for the future data rates. noitemsep

- Data rates should be increased by approximately thousand times for each area unit.
- The worst reasonably expectable user data rate should range from 100 Mbps to 1 Gbps. At the moment this value is around 1Mbps so the advance must be at least hundred fold.
- Best possible rate, while mostly a marketing number, should also be increased greatly, to tens of gigabits per second.

Fourth generation radio access networks offer roundtrip latencies of around 15 ms. It is stated that current applications can tolerate this well but some of the applications visioned for the era of 5g networks need faster response times. Roundtrip latency of around 1ms should be delivered.

It would obviously be ideal to reduce energy and financial costs but it is stated that this isn't on the top of requirements of 5g. It is, however, required that the costs wouldn't rise. In practise this means that as data rates are increased by for example a factor of hundred, energy and monetary cost per bit should be reduced to one percent of the current cost to keep the overall cost constant.

The paper lists ultra-densification, mmWave and massive multiple-input multiple-output (MIMO) along with virtualization as the defining factors of future radio access networks. The combination of these approaches are seen as the keys to provide ubiquous, high-rate, low-latency connections to all mobile users.

Densification means simply making cells served by a radio access node smaller. This approach has been used in previous radio access improvements and ultra-densification just means taking it to yet another level. The most important benefit of this approach is that spectrum reserved by a user connection via a basestation accommodates a smaller area. In other words, smaller coverage area per basestation means less users connecting via that particular basestation. Obviously this means that there are more basestation resources available for each user. This approach doesn't come without downsides. Some of the associated challenges listed are supporting mobility between cells and increased costs of installing and maintaining all the basestations.

IV. Effects of Improved Radio Access Networks

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V. Conclusion

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References

[1] N. Fernando, S. W. Loke and W. Rahayu, *Mobile cloud computing: A survey*. Future Generation Computer Systems Volume 29 Issue 1, January 2013.

[2] Y. Wang, I. Chen and D. Wang, *A Survey of Mobile Cloud Computing Applications: Perspectives and Challenges*. Wireless Personal Communications: An International Journal Volume 80 Issue 4, February 2015.

[3] M. Miluzzo, R. Cceres and Y. Chen, *Vision: mClouds Computing on Clouds of Mobile Devices* . MCS '12 Proceedings of the third ACM workshop on Mobile cloud computing and services, 2012.

[4] G. Chatzimilioudis, A. Konstantinidis, C. Laoudias and D. Zeinalipour-Yazti, *Crowdsourcing with Smartphones*. IEEE Internet Computing Volume 16 Issue 5, September 2012.

[5] M. Satyanarayanan, P. Bahl, R. Caceres and N. Davies, *The Case for VM-Based Cloudlets in Mobile Computing*. IEEE Pervasive Computing Volume 8 Issue 4, October 2009

[6] A. Gohil, H. Modi and S. K. Patel, *5G Technology of Mobile Communication: A Survey*. Intelligent Systems and Signal Processing (ISSP) International Conference, 2013

[7] J. G. Andrews, S. Buzzi, W. Choi, S. V. Hanly, A. Lozano, A. C. K. Soong and J. C. Zhang, *What Will 5G Be?*. IEEE Journal on Selected Areas in Communications Volume 32 Issue 6, June 2014