

Virtual Wireless User: A Practical Design for Parallel MultiConnect Using WiFi Direct in Group Communication

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Abstract. Several MultiConnect technologies are actively discussed in research today. MultiPath TCP (MPTCP) is capable of splitting one flow into subflows and balance the load across multiple access technologies. Multihoming is an older technology that makes it possible for network providers to balance load across multiple up- and down-links dynamically. Finally, Software Defined Networking (SDN) achieves the ultimate flexibility of connection and routing decisions. However, none of these technologies enable true (network or otherwise) resource-pooling in communications within arbitrary size user groups such as occur in meetings, class discussions, and ad-hoc communities in the wild. This paper proposes the concept of a Virtual Wireless User (VWU) which represents the entire group and appears as single user to an over-the-network service. Each group member is capable of MultiConnect using Wi-Fi Direct in parallel with any other connection method. Modeling based on real measurements shows that VWUs can achieve throughput in the order of tens of Mbps even if throughput of individual users is very low. The paper also formulates a formal optimization problem in relation to VWU.

Keywords: Virtual wireless user · Connectivity virtualization · Network access virtualization · MultiConnect · MultiPath · MultiHoming · Wi-Fi Direct · P2P Wi-Fi · Resource pooling · Group communication

1 Introduction

Many things are given the prefix *multiple* in networking today. First, there is the old yet currently active topic of *multihoming* [1]. RFC6182 recently defined MultiPath connectivity which can be implemented as MultiPath TCP (MPTCP) [3]. Dynamic connectivity can also be achieved using Software Defined Networking (SDN) [8]. All these methods share the following common features:

- there is one content (file, flow, etc.);
- there is one source (destination of an end-to-end path);

- the one content is communicated between the user and the source via multiple parallel paths.

The main problem is that the above features are insufficient when describing a large set of applications. For example, traditional multipath technology cannot help communications within a group of users, where the new formulation is:

- the unit of content is its small piece (block, one file of many, etc.) [7];
- each unit of content can have at least two but potentially a large number of sources [12];
- there are multiple parallel paths as before, but paths are dynamically configured to connect to sources decided on the fly.

The new design (the one that fits the above new formulation) should have the following required components. Each user should have at least one of each *inter-* and *intra-*net connectivity – it is technically possible to work with one connectivity method but this would defeat the purpose. The *intranet* connection is expected to carry larger throughput than its *internet* counterpart. A *Virtual Wireless User* (VWU) is then defined as a virtual entity/application which pools all resources and performs load balancing between intra- and inter-nets. While traditional multipath technologies can double or at most triple throughput in practice, this paper shows that VWUs can theoretically feature arbitrarily large throughputs from the aggregate pools of singular connections.

There are several example applications which are done in groups of users. It can be a meeting of users gathered in a room, a class discussion, or an arbitrary size ad-hoc community gathering anytime anywhere. As long as resources within the group are controlled by a single application, the VWU can be created to represent the group before a Service Provider (SP).

Note that *MultiConnect* (properly defined further on) does not explicitly require a connection-based transport protocol. For example, Delay Tolerant Networks (DTNs) can work with strict delay constraints [11] and can be used as the transport protocol within the *intranet*. In this case, content is exchanged in blocks or files [7].

Wi-Fi Direct is a recent technology [16] which makes it possible to create DTN-like intranets. It is also referred to as Wireless P2P [16]. Wi-Fi Direct pursues two objectives: (1) provide fast AP-less communication between two users, which is achieved by implementing lightweight APs inside users [16], and (2) facilitating ubiquity by minimizing overhead, for example, making it possible to have a continuous pairing with a printer [16]. While Wi-Fi Direct is like DTN in that the unit of exchange is a file, the specifications allow for a continuous operation which can support one-hop flows. Note that Wi-Fi Direct itself is not a MultiConnect technology where the latter needs an entire new application layer on top of the raw connectivity options provided by Wi-Fi Direct.

This paper makes the following contributions: (1) it is shown how Wi-Fi Direct can be used as a building block for a MultiConnect technology in group communications; (2) it is shown that Wi-Fi Direct is already fully implemented

in practice today while multipath technologies are at early development stage; (3) results from real life measurements in combinations of 3G and WLAN with Wi-Fi Direct technologies are presented and analyzed; (4) MultiConnect of 3G and WLAN with Wi-Fi Direct is tested in practice and analyzed for throughput in parallel operation; (5) the Virtual Wireless User (VWU) is formulated and several models with VWU and an example optimization problem are presented.

2 Terminology and the Scope

Wi-Fi is difficult to type so it is shortened to *WiFi*. Traditional WiFi is *WLAN*. *3G* is the umbrella term for 3G, LTE and all other 3.xG cellular technologies.

Communication is classified into the two fundamental types of *connection-based* versus *hop-by-hop*, where the former can be represented by TCP and the latter by Delay Tolerant Networks (DTN) [10]. *Group communication* stands for an application in which members of a group communicate among each other. In this context, *intranets* connect all the users while *internets* connect each user to a Server Provider (SP) individually.

Multi-* technologies are classified into *multihoming*, *multipath* and *MultiConnect*, where the last one is formulated for the first time in this paper (to the extent of this author's knowledge). MultiConnect is distinct from the other two technologies by having unique features (explained earlier), thus justifying the new term. Specifically, in this paper MultiConnect is defined as ability to use multiple access technologies in parallel. Note that this formulation is not sufficient for *multipath* which requires all access technologies to support end-to-end paths to the same destination. The *MultiConnect* has no such requirement.

Service Provider (SP), *Wireless User* (WU) and *Virtual Wireless User* (VWU) are the main three players in the scope of this paper. Remote players are Network Provider (NP or ISP), Content Provider (CP) and clouds.

3 Related Work

Multihoming is an old technology which has received renewed attention in view of high-throughput networking in CDNs [1]. By contrast, there are many multipath technologies considered in research today [2], ranging from I-WLAN and IFOM (3GPP) to MultiPath TCP (MPTCP), SCTP (RFC2960) and IMS method with its multipath RTP. MPTCP is leading in terms of implementation for which there is already a Linux kernel [4] tested in practice [3], but even MPTCP is much less widespread in devices today compared to WiFi Direct. MPTCP has been analyzed for performance as a resource pooling technology in environments with one source [6], while the *MultiConnect* technology presented in this paper uses multiple sources. MPTCP is still under active discussion in RFC6181, RFC6182, RFC6356, RFC6824, and RFC6897, where RFC6182 presents the fundamentals of the technology.

Network virtualization is not considered in existing research on multipath. Virtual networks are supposed to provide truly flexible routing and path establishment decisions – executed in software. Software Defined Networks (SDNs) with OpenvSwitch as the de-facto standard [8] are assumed to make routing decisions at the grain of individual packets. SDNs were shown to be slower than traditional networks, but slightly diminished performance is not a problem for end users [15]. ClickRouter [9] is a non-SDN way to make per-packet routing decisions and is very active in research today. SDN was tried in a multipath implementation at least once in [5] as part of a very crude implementation which installs Linux and then OpenvSwitch onto an originally Android smartphone.

Note that none of the above technologies consider resource pooling in groups. The resource pooling problem was originally proposed as part of distributed-sync (dsync) [7]. The proposal is for group communication but does not use MultiConnect – instead, users have only one connection at a time.

In MultiConnect, congestion of wireless channels may pose a practical issue. Although channel congestion is out of scope of this paper, experiments in [13] show that one channel can be shared by many users with minimum effect on throughput up to a given point. Research in [13] can also serve as a reference into other research on this issue.

When content grain is a block of data or a file, DTN formulation is applicable [10]. RAPID is the most efficient DTN method today [11]. Under RAPID, latency-constrained delivery is possible. The method can be further improved when bandwidth is unreliable. Note that while DTN is a generic principle, group communications are not necessarily dynamic and unpredictable in practice. For example, people having a meeting in- or out-doors should not be difficult to work with. Such environments are perfect for WiFi Direct.

4 Practical Parallel Group MultiConnect

Figure 1 presents the taxonomy of practical MultiConnect reality today. The presentation is simple and shows two features: default technology in a pair and ability to use a technology in parallel with WiFi Direct. The simple message is that WiFi Direct can work with any common access technology including the LAN. Current support for WiFi Direct is limited in notebooks and desktops, but it is implemented by many smartphones and tablet computers.

Figure 2 shows the first abstraction leading to the main VWU formulation. The figure simply shows that users are connected to both intra- and inter-nets. We do not care about throughput for now. MultiConnect in this context is in that each user has at least two separate parallel connection methods. The design offers some side benefits as well. Even if some users have no internet connectivity, they can be supported by the intranet, where the latter are supposed to be faster by definition and thus facilitate situations when some users are supported by others in a group.

Figure 3 is the second abstraction, this time more about pooling of resources. VWU is positioned on the border between SP and users and is the single/only

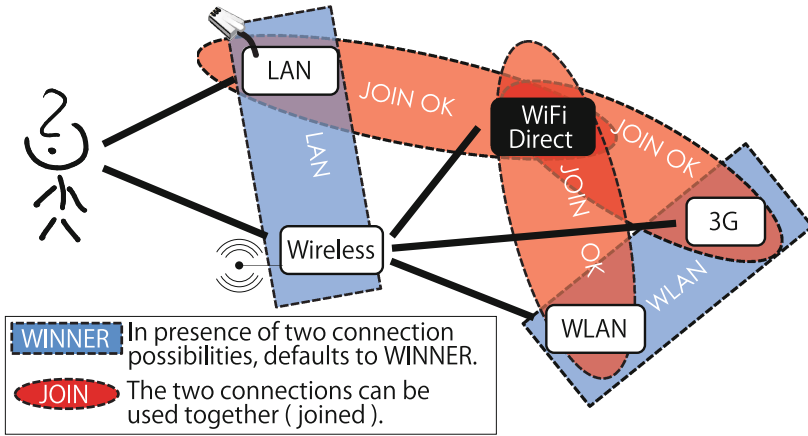


Fig. 1. Taxonomy of existing connectivity technology viewed in the practical aspect of parallel usage.

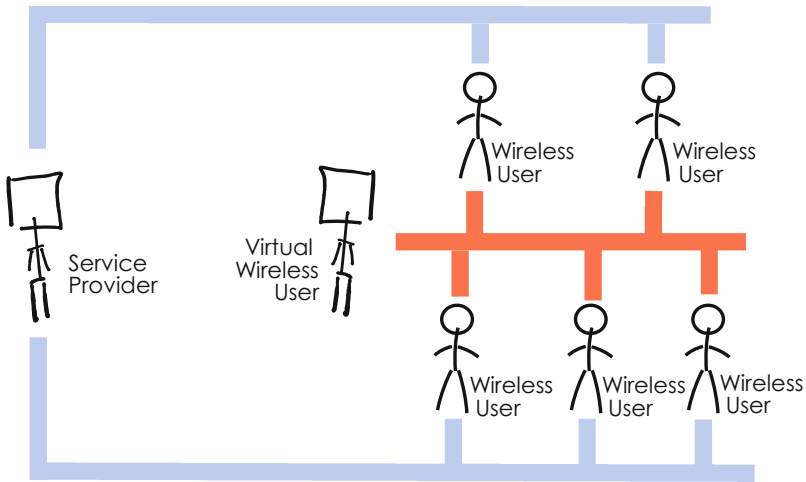


Fig. 2. Abstraction 1: Virtual Wireless User (VWU) made possible when members of a communication group support an *intranet* in parallel with each individual traditional *internet* connections.

contact person as far as SP is aware. Figure 3 also shows that throughput is important. SP-VWU throughput is the aggregate of internet connections of all users. VWU-WU aggregate throughput is the maximum throughput achieved by WiFi Direct inside the group, given the interference, etc.

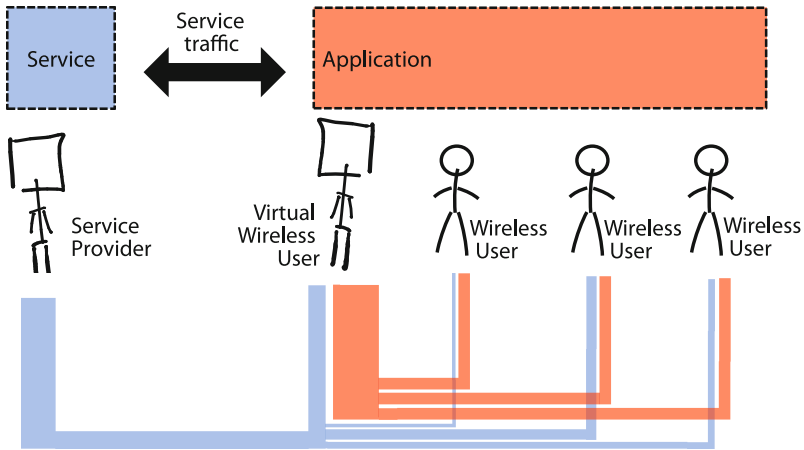


Fig. 3. Abstraction 2: A redesigned Abstraction 1 in such a way as to show that *service traffic* is exchanged only between the Virtual Wireless User (VWU) and Server Provider (SP) while VWU and the application it executes takes care of the communication within the *intranet*.

5 Measurements in Real Inter- and Intra-networks

This section presents real measurements for all technologies involved in the proposed MultiConnect as well as their parallel configurations. For 3G, day of week and time of day are important because ISP resources are contested by a large number of users, while WLANs merge into LANs for end-to-end traversal.

5.1 Internets: Real 3G Providers

The objective of this batch of measurements is to analyze 3G performance for several real providers. Three 3G providers (names omitted) were selected, where one provider limited throughput to 300 kbps under the contract, but the other two were supposed to provide full (best effort) capacity. The test ran continuously over the period of 3 months from mid-April 2013 with several tens of measurements collected every day. When presenting results, days are classified into Holiday 1 (Sunday), Holiday 3+ (longer holidays), Saturday, and Workday. Measurements were careful not to run over quota (2 Gb each month).

Each measurement result was obtained as follows. A 500 kb file was downloaded from a fixed server. Throughput is then measured by dividing 500 kb (x8 bits) by the download time in seconds.

Figure 4 shows measurement results. Lessons are obvious. The maximum achievable throughput is 1 Mbps but only occurs for one of three ISPs, while the other two feature very low throughput. There is great variation across hours of day and types of days.

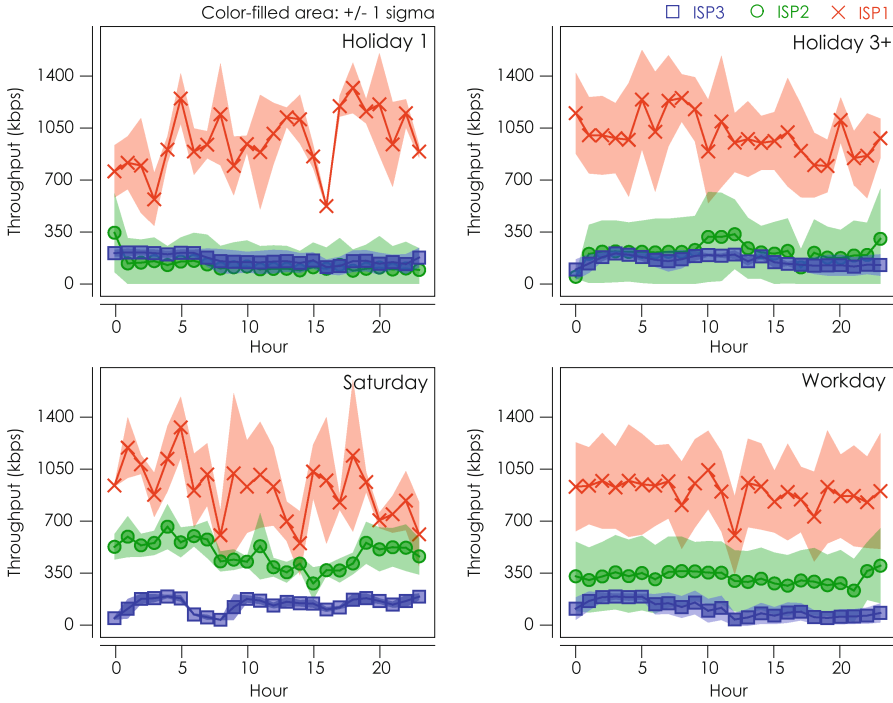


Fig. 4. Throughput performance for the three 3G ISPs split into the four kinds of days of the week. Color-filled areas are 1 sigma bands.

5.2 Intranets: WiFi Direct and Bluetooth

The objective of this batch of measurements is to compare the two available technologies in the intranet – WiFi Direct and Bluetooth 4.0. In a single measurement, 1, 5 or 10 files (max bulk size slightly above 1 Gb) are transferred between two smartphones. Distances of 1 m and 10 m are tested separately.

Figure 5 shows the results. WiFi Direct is clearly superior to Bluetooth, as much as 30 times better as shown in the second plot. However, distance has some effect on throughput and can cause up to 40% decrease in throughput for extended sessions.

5.3 MultiConnect Performance

The objective of this batch of measurements is to cross WiFi direct with 3G or WLAN and test both in parallel, thus creating the first true *MultiConnect* in this paper. The same setup is used the same as in the previous case, only the sessions are parallel and end when the intranet connection completes.

Figure 6 has two features. WiFi Direct throughput is affected very little when used in parallel with a 3G connection while parallelization with WLAN can

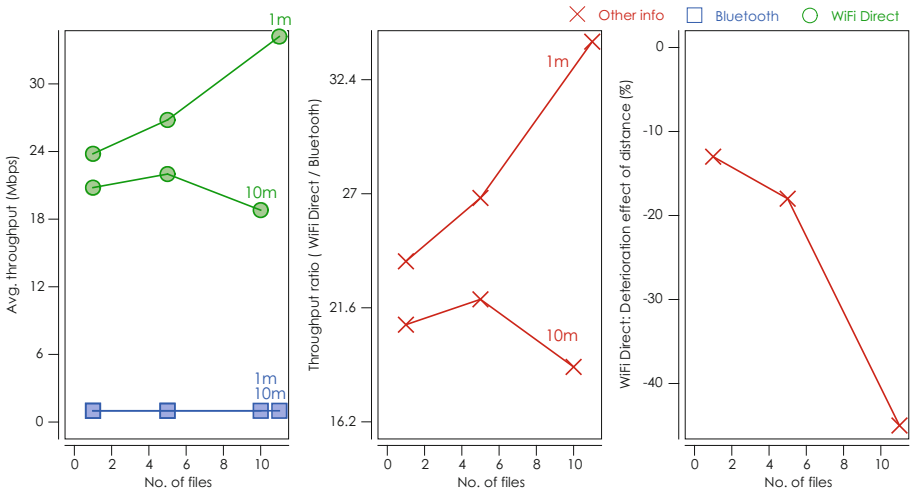


Fig. 5. Comparison of throughput in WiFi Direct versus Bluetooth 4.0 environments. Second and third plots present throughput ratio and the effect of throughput deterioration with distance in WiFi Direct.

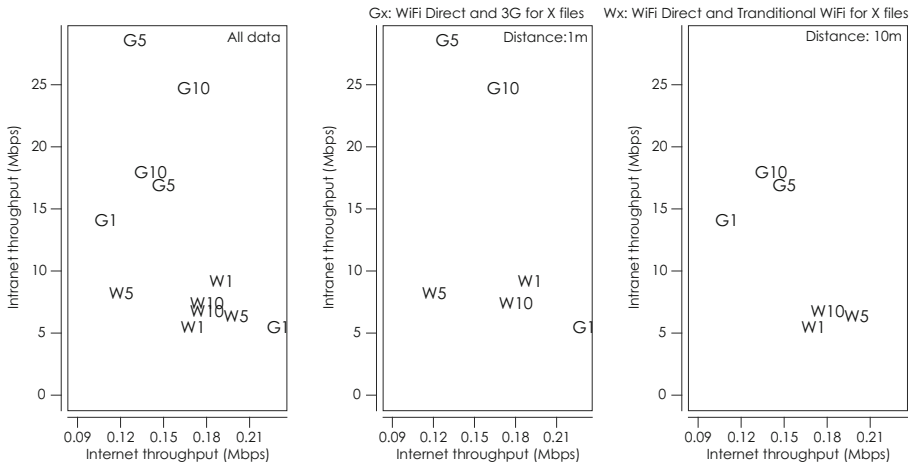


Fig. 6. Performance during MultiConnect where interference cannot be avoided. MultiConnect is compared in two configurations: *WiFi Direct with 3G* and *WiFi Direct with Traditional WiFi (WLAN)*. *W* stands for WLAN and *G* for G3, both used together with WiFi Direct.

greatly diminish throughput. Also, there is a clear inverse relation between intra- and internet throughputs. In fact, the first feature might be a subset of the second since G3 throughput is lower in real networks.

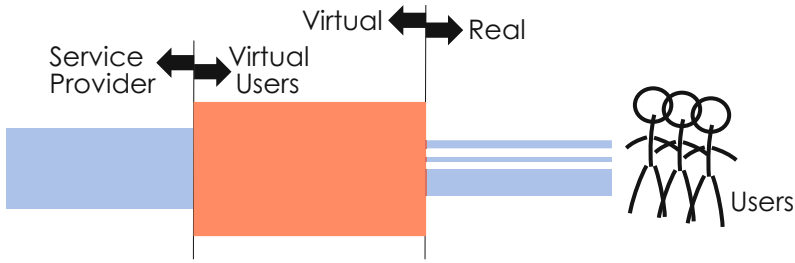


Fig. 7. The concept of throughput piping. Thickness represents achievable throughput.

6 Practical Formulations

The objective of this section is to formulate the resource pooling side of the proposed MultiConnect. Measurement results presented in the previous section are used for modeling. Finally, this section presents an example optimization problem based on the proposed design – a group sync with a cloud drive. Note that there can be numerous optimization formulations depending on a specific application. Also note that the VWU itself is based on a generic design which is intended to be application-independent.

6.1 Abstraction 3: Throughput Piping

Figure 7 is the final abstraction which now fully describes the role of VWU. The virtual section (middle) is used as a pipe between SP and Users. As before, intranet capacity is normally the largest in the pipe, even larger than the maximum achievable (end-to-end) throughput from SP. On the right side, the virtual section space is plugged with individual internet connections contributed by users. The objective is as was stated before – to balance between the intranet and internet traffic given the current leftover capacity in each.

6.2 Virtual Wireless User: Performance Margins

Performance model of the VWU is created as follows. First, best and worst cases are extracted from measurement data. For 3G, the data is grouped in hours of day. The other view is by the interference where higher intranet throughput inversely affects internet throughput and visa verse. Finally, the best and worst cases are analyzed relative to the throughput performance detected for WiFi Direct in measurement. This produces the single-user baseline, which is then expanded by multiplying by the number of users, up to 25, in order to emulate a range of groups from small to relatively large.

Figure 8 presents the results for the two views. The left side shows that the best case does not exceed WiFi Direct capacity even for 25 users. Note that the left side is based on real measurements without MultiConnect. The right side adds MultiConnect and shows that the best case stays below 25% of

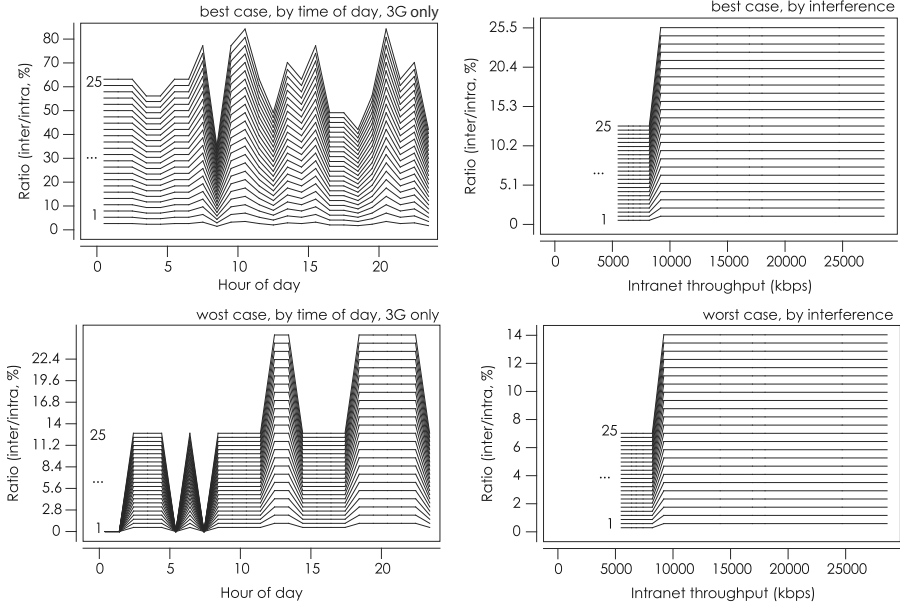


Fig. 8. Best and worst cases of performance projected for between 1 and 25 users inside the VWU.

WiFi Direct capacity even in the best case and under 15% in the worst. The results support the *piping* model presented above and shows that WiFi Direct is difficult to overwhelm in realistic networking environments.

6.3 Virtual Wireless User: An Example Optimization Problem

Let us use U and C to denote *utilization* and *capacity*, respectively. $C_{network}$ would then denote *network capacity* and C_{cpu} CPU capacity (multi-core, etc.). $C_{i,inter}$ notation can be used to denote internet capacity of user i . L denotes *load* of a node – a generic metric describing processing overhead. The metric $diff$ can be used to denote sync diffs, measured in bytes or chunks of data to be updated. Finally, T denotes the time interval for one optimization cycle.

The optimization problem for a *group sync* based on a cloud drive (Google Drive, Dropbox, etc.) can then be written as:

$$\text{minimize } w_1 \sum_{i \in \text{group}} diff_i + w_2 \sum_{i \in \text{group}} L_i + w_3 \sum_{i \in \text{group}} \frac{U_{i,network,sky}}{U_{i,network,floor}}, \quad (1)$$

where

$$L_i = U_{i,cpu} + U_{i,network} \quad \forall \quad i \in \text{group}, \quad (2)$$

subject to

$$L_i \leq 2 \quad \forall \quad i \in \text{group}, \quad (3)$$

$$\text{sizeof}(\text{merge}(\{\text{diff}_i\})) \leq T \sum_{i \in \text{group}} C_{i,\text{out},\text{network}}. \quad (4)$$

Clearly, it is a linear problem. However, weight setting (w_1 and w_2) is a side problem which needs to be considered when looking for a solution. Note that the merged size of *diffs* is limited by the sum of capacities on Internet connections to ensure that continuous operation can be sustained. If the constraint in (4) is not satisfied in several successive optimization cycles, backlog of unsynced changes may start growing exponentially and uncontrollably.

Note that the third term in (1) minimizes 3G traffic by giving higher weight to intranet communications, as long as diffs are property synced between local and cloud storages. Practical validation for the above problem is out of scope of this paper but will be presented in future publications. However, it is important to note that the optimization problem is drastically different from the one in [7] and technologically different from the traditional multipath.

7 Conclusion

This paper is the first to formulate both the *MultiConnect* design and propose a Virtual Wireless User which exploits MultiConnect – another new concept proposed in this paper – for resource pooling in group communications. Using WiFi Direct, each user can maintain traditional internet connections in parallel with intranet connections based on WiFi Direct. Since WiFi Direct is closer to the DTN communication paradigm, traditional multipath – where multiple paths are between the virtual wireless user (VWU) and remote service – is emulated using a given data grain, namely blocks of binary data, files, etc.

In this paper, real networking environments are measured and used to create realistic VWU models where the latter show that even groups up to 25 users each with its own 3G or traditional WiFi connection cannot overwhelm the intranet capacity provided by WiFi Direct.

VWU was also shown as a formal optimization problem independent of technologies in underlying connectivity. Using the formal problem, it is possible to create a VWU on top of any combination of connectivities and any organizational structure among users.

Future work will present implementation of the generic VWU application engine for smartphones and tablet devices. The two specific practical usecases that will be considered in future publications are the use of VWU for streaming in wireless networks and MultiConnect at the level of browsers where the latter have been shown recently in [14] to support multicore architectures and near-gigabit aggregate throughput.

References

1. Hau, T., Burghardt, D., Brenner, W.: Multihoming, content delivery networks, and the market for internet connectivity. *Elsevier J. Telecommun. Policy* **35**, 532–542 (2011)
2. Schmidt, P., Merz, R., Feldmann, A.: A first look at multi-access connectivity for mobile networking. In: *ACM Workshop on Capacity Sharing (CSWS)*, pp. 9–14 (2012)
3. Chen, Y., Lim, Y., Gobbens, R., Nahum, E., Khalili, R., Towsley, D.: A measurement-based study of MultiPath TCP performance over wireless networks. In: *ACM SIG-COMM Internet Measurement Conference (IMC)* (2013)
4. MultiPath TCP: Linux Kernel Implementation. <http://multipath-tcp.org>. Accessed October 2013
5. Yap, K., Huang, T., Kobayashi, M., Yiakoumis, Y., McKeown, N., Katti, S., Parulkar, G.: Making use of all the networks around us: a case study in android. In: *ACM SIGCOMM Workshop on Cellular Networks: Operations, Challenges, and Future Designs (CellNet)*, pp. 19–24 (2012)
6. Makela, A., Siikavirta, S., Manner, J.: Comparison of load-balancing approaches for multipath connectivity. *Elsevier J. Comput. Netw.* **56**, 2179–2195 (2012)
7. Pucha, H., Kaminsky, M., Andersen, D., Kozuch, M.: Adaptive file transfers for diverse environments. In: *USENIX Annual Technical Conference*, September 2013
8. OpenVSwitch project. <http://openvswitch.org/>. Accessed August 2008
9. Kohler, E., Morris, R., Chen, B., Jannotti, J., Kaashoek, M.: The click modular router. *ACM Trans. Comput. Syst. (TOCS)* **18**(3), 263–297 (2000)
10. Vasilakos, A., Zhang, Y., Spyropoulos, T.: *Delay Tolerant Networks: Protocols and Applications*. CRC Press, Boca Raton (2011)
11. Balasubramanian, A., Levine, B., Venkataramani, A.: DTN routing as a resource allocation problem. In: *SIGCOMM*, pp. 373–384, October 2007
12. Zhanikeev, M.: Multi-source stream aggregation in the cloud. In: Pathan, M., Sitaraman, R.K., Robinson, D. (eds.) *Advanced Content Delivery and Streaming in the Cloud*, Chap. 10. Wiley, New York (2013)
13. Zhanikeev, M.: Experiments on practical WLAN designs for digital classrooms. *IEICE Commun. Express (ComEx)* **2**(8), 352–358 (2013)
14. Zhanikeev, M.: Experiments with application throughput in a browser with full HTML5 support. *IEICE Commun. Express* **2**(5), 167–172 (2013)
15. Zhanikeev, M.: Experiences from measuring per-packet cost of software defined networking. *IEICE Tech. Rep. Serv. Comput. (SC)* **113**(86), 31–34 (2013)
16. *Wi-Fi Peer-to-Peer: Best Practical Guide*, Wi-Fi Alliance, December 2010