CloudBridge: A Cloud-Powered System Enabling Mobile Devices to Control Peripherals Without Drivers

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ABSTRACT

Smart devices including smart phones and tablets are getting more powerful and become versatile enough to replace conventional personal computers. Despite the rapid evolution of capabilities of such devices, controlling peripherals such as networked printers is infeasible due to lack of dedicated drivers to communicate with peripherals. To immediately enable smart devices to operate peripherals, we propose a cloud-powered system, CloudBridge. CloudBridge user application running on a smart device works as a TCP bridge relaying packets between two TCP tunnels connected to a networked peripheral on one side and a cloud server on the other. Through the bridge, it is possible to issue operations from a smart device without having dedicated drivers by asking the cloud server to interpret the operations to a language that the peripheral can understand. CloudBridge further optimizes user experience through data compression which is adaptively applied based on decision functions. The system is implemented on Android devices and a Linux server, and we demonstrate that it perfectly controls networked printers on smart devices. The decision functions are shown to provide optimized QoE metrics such as response time and energy consumption though extensive evaluations.

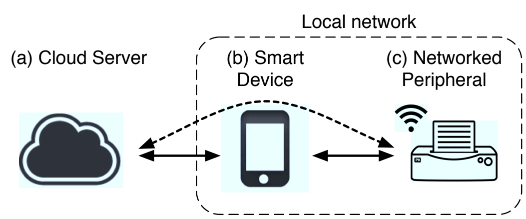


Figure 1: The smart device in the middle works as a bridge connecting a cloud server and a networked peripheral in local at each side through TCP tunnels.

1. INTRODUCTION

Smart devices are becoming prevalent in our lives. According to a report [3], the total shipments of smart phones and tablets during 2011 were 550.9 million units. The number is higher than 351.4 million units, the total shipments of conventional personal computers (PCs) including desktop, laptop, and netbook. While the market for smart devices is growing dramatically, the capabilities of such devices have also been revolutionized during recent years. Many survey results from business sectors [2, 3, 13] show that smart devices started to replace conventional computers in daily computing leveraging their unique strengths such as dedicated applications, faster operations via finger touches, lighter weight, and longer battery time. However, there is a critical limitation of smart devices in replacing conventional computers. That is lack of peripheral support. Smart devices are not able to communicate with peripherals such as networked printers, scanners, cameras because the manufacturers of such peripherals do not provide dedicated drivers for smart devices. The limitation can be mitigated by waiting the manufactures to release dedicated drivers or porting drivers developed for PCs to smart devices. However, both approaches are not universally applicable to all peripherals. To address this problem, we propose a networked system leveraging cloud computing, which we call *CloudBridge* for smart devices.

CloudBridge enables peripheral support in smart devices in a way that is *universally applicable* and completely *independent* from local PCs. It also provides *indistinguishable* experiences to users when controlling peripherals comparing to that from a conventional PC. CloudBridge system consists of an user application for smart devices and a daemon for a cloud server. As shown in Figure 1, the application running on a smart device sets up TCP sockets with a networked peripheral and a cloud server. Using the sockets connecting both sides, CloudBridge makes a smart device as a transparent bridge allowing the cloud server with an appropriate driver to communicate with the peripheral. Since the cloud server is assumed to have drivers for most of the peripherals in the market and is controlled by the application, the peripherals become immediately accessible from smart device users. We apply the proposed system to operate networked printers throughout this paper, but one should note that this technique is not limited to printing but applicable to wide variety of peripherals equipped with networking capability.

Despite its simple yet efficient system architecture, Cloud-

Bridge encounters a critical challenge for its practicality. The cloud server which operates as an interpreter between the user application and the peripheral interprets a file into a print stream written in the printer language, PCL (printer command language), using a proper driver that the target printer can understand. A challenge observed here is that the size of the generated print stream becomes huge ranging from several times to a few hundred times of the original file size. Given that our system relies on networking to deliver the stream to the printer, the increased size directly affects the user experiences such as total print time and energy consumption on the smart device.

To address the challenge, we investigate the characteristics of print stream and adopt a compression technique, which shows the best compression efficiency for the print streams. Applying compression brings trade-off between the total print time and the energy consumption because compression and decompression demand time as well as energy. For the optimal use of compression, we model decision functions which determines whether to apply compression or not based on two aforementioned criteria. We perform extensive experiments with more than a thousand printer models from major printer vendors, whose drivers are installed in our cloud server. The results show that the ratio between the total print time of our system and the time using a conventional PC converges to $B_p/B_c + 1$ as the file size gets larger, where B_p and B_c denote the network bandwidth to the printer and to the cloud server, respectively. Also, our decision functions are verified to provide satisfactory user experience in 95% of the time.

Our contributions in this paper include the followings.

- We propose a cloud-powered network system, CloudBridge, enabling peripheral support in smart devices.
- We implement the system in Android smart devices and a Linux server, and demonstrate the efficacy of the system for printing.
- We identify a challenge in the system and suggest a practical solution by adopting a compression technique and its optimal decision function.

The paper is organized as follows. In Section 2, we summarize existing approaches which target peripheral support in smart devices. We present detailed system architecture and implementation issues of CloudBridge in Section 3. In Section 4, we validate our implemented system through extensive evaluation and analysis, and introduce compression technique in Section 5 for system optimization. Finally, we conclude the work in Section 6.

2. RELATED WORK

In this section, we focus on techniques providing a specific peripheral support, printing from smart devices. There have been various techniques enabling printing from smart devices, but the existing techniques do not perfectly achieve our goals, *independent*, *complete*, and *universal* peripheral support for smart devices. We survey the techniques and discuss about them in detail.

Printer driver is a software that converts digital data into bit streams, which can be understood by a printer. To operate a printer on a PC, the driver should be installed beforehand. If the printer vendors do not provide dedicated drivers to smart devices, there is no intuitive way to operate printers directly from smart devices. To address the problem, various approaches have been tried. The fact that there are over 300 printing applications in Android Market shows high demand of a solution from users. Printing solution available in the market are classified into three categories: 1) printing through a PC connected to a printer, 2) printing through a mobile driver ported from PC, and 3) directly printing using a special printer.

(1) Printing via a PC.

Most of the applications listed in mobile application markets make use of a local PC directly connected with a printer via wired or wireless connection. Such applications send a file to the computer and ask to issue print command. Apple's AirPrint [1] and Google's CloudPrint [5] adopt this approach. Many Android applications that support mobile printing exploit the CloudPrint service. This approach requires setup procedure in advance and the relaying PC to be always turned on waiting for the request. We consider this approach does not meet our goal, *independence*.

(2) Using ported drivers.

To enable independent operation from PC when printing from smart devices, several companies such as PrinterShare [11] and Samsung [12] provide applications which contain printer drivers ported for smart devices. This approach immediately allows smart devices to operate printers, but the number of supported printer models is very limited. Also, functional limitations may exist since the drivers are not dedicated especially when the conversion is not provided by the vendors. Some proprietary functions may not be accessible. This approach lacks *universal* support.

(3) Using driver-less printers.

Another approach mainly provided by printer vendors is printing a file directly at the printer without any help of PC or smart device. It is called *driver-less printing* and vendors recently launched a set of printers supporting this feature. When smart devices send a file to the printer over network, the printer itself interprets the file into bit streams it can understand. HP ePrint printers [6], Kodak Hero series [9] and the latest Epson models [4] are the representatives. This approach is desirable in that it does not put any burden to smart devices. But it cannot provide *universal* support as most of the printers does not have the driver-less printing feature. More importantly, it has a fundamental limitation in supporting various file types, lacking *completeness*. The driver-less printers may only support basic formats such as text (TXT,

Solutions	Independence from PC	Complete file type support	Universal printer support
Printing via a PC [1,5]	×	○	○
Using ported drivers [11,12]	○	×	×
Driver-less printers [4,6,9]	○	×	×
CloudBridge	○	○	○

Table 1: Mobile printing solutions in the market and their characteristic classification based on three criteria. CloudBridge satisfies all key features: it provides independent, complete, and universal peripheral support.

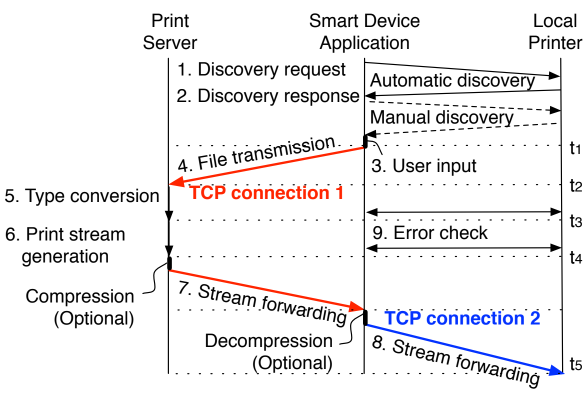


Figure 2: The communication sequence of CloudBridge.

Algorithm 1 Pseudo operations of CloudBridge application

if *Printer search* button selected **then**
  List the automatic discovery result
  if A printer name selected from the list **then**
    Set the printer as target device
  else if An IP address entered **then**
    Operate manual discovery and set as target device
  end if
else if *File search* button selected **then**
  List files in the SD card storage
  Set the selected file to print
else if *Print start* button selected **then**
  if Target printer and file to print set **then**
    Start *printing process*
  end if
end if
Printing process:
Set up TCP socket $sock_1$ with cloud server
Transmit target printer information and file to server
Set up TCP socket $sock_2$ with local printer
if Compressed print stream **then**
  Receive entire data from server through $sock_1$
  Decompress data into raw print stream
  Transmit stream to printer through $sock_2$
else
  while Receive packet from server through $sock_1$ **do**
    Transmit packet to printer through $sock_2$
  end while
end if
return

RTF), image (BMP, JPEG), but not the advanced formats widely used, e.g., Encapsulated PostScript (EPS), Windows Metafile (WMF), and Adobe Photoshop (PSD).

Table 1 summarizes features of the existing printing techniques compared with CloudBridge system. As shown in the table, our approach relying on the cloud server satisfies all key features: it provides independent, complete, and universal peripheral support.

3. CLOUDBRIDGE SYSTEM

CloudBridge contains two major entities: an user application for smart devices and a daemon running on a cloud server. In our system, the bidirectional TCP bridge lying between two entities is the key component. Through this bridge, the user application can control the networked peripherals with the help from the cloud server.

3.1 Operations

CloudBridge consists of 9 steps of operations between a CloudBridge user application, a server daemon, and a printer as illustrated in Figure 2. (1) A smart device broadcasts a discovery request to all hosts on the same subnet or sends query directly to an IP designated host. (2) On receiving the query, printers send responses back containing their device information. (3) On receiving the responses, the application asks the user to select a printer and a file to print, and (4) delivers them all together to the cloud server. (5) On receiving the file and the printer information, the daemon first checks the file type. If the file type is of advanced applications, the file handling module converts the file into a basic format. (6) Once the conversion is done, the stream handling module interprets it into a print stream. (7) The stream handling module determines whether to compress the stream or not based on the network bandwidth and the size of the stream. This module then sends the print stream, either after compression or not, back to the smart device through the TCP connection established in step 4. (8) On receiving the stream, the smart device decompresses it if compressed. Then, the device delivers the raw stream to the printer by setting up a new TCP socket. (9) Along with the processes 1 through 8, the smart device application periodically sends out error queries to the printer to check the error status such as lack of paper/toner or

Algorithm 2 Pseudo operations of CloudBrindge daemon

```
while Accept connection from client do
    Receive printer information and file
    if Printer driver matching failed then
        Transmit error message to smart device
        return
    end if
    Register printer by redirecting the stream to localhost
    if File type is advanced application then
        if File type is web address then
            Trigger web file generation to file handling module
        else
            Trigger file type conversion to file handling module
        end if
        Receive converted file from file handling module
    end if
    Generate print stream by issuing print command
    while Receive packet from localhost do
        Receive entire raw print stream
    end while
    if Decision function returns 1 then
        Compress the raw print stream
        Transmit compressed stream to client
    else
        Transmit raw print stream to client
    end if
end while
```

incident of paper jam, and pops instant feedback to the user. Besides that, the smart device also forwards printer errors to the cloud server and gets error interpretations back, similar to what the stream handling module does.

Algorithm 1 and Algorithm 2 summarize the work flow of the CloudBridge application and server, respectively.

3.2 System Architecture

Figure 3 shows the software architecture of two components, CloudBridge user application and server daemon.

(1) Smart device application.

- The user interface module collects user inputs regarding target printer information, printing options (e.g., color, duplex), and the preferred performance metric (e.g., print time, energy consumption). This module also receives notification messages from the printer as well as the server (e.g., low toner, no paper) and interprets them in human-readable format. It basically communicates with the networking module to deliver all information.

- The networking module consists of two sub-modules, peripheral discovery and data relay module. The discovery module uses well-known service discovery protocols such as multicast-DNS (domain name system), DNS-SD (DNS-based service discovery), SSDP (simple service discovery protocol) to find nearby printers, especially located in the same subnet. The module can extend its discovery boundary by specifying an public IP address of the target printer using SNMP (simple network management protocol) queries. The data relay module is the key component to bridge packets between two end points. Whenever there are packets coming from one side, it extracts payloads from these packets and then forwards them to the other side. If the data is determined to be notification message, it passes it to the user interface module.

- The stream handling module verifies whether the received stream is compressed or not. It selectively performs decompression only when the payloads are in the compressed form. Since the decision on compression is made at the cloud server, this module passively decompresses the stream and returns raw print stream back to the networking module.

(2) Cloud server daemon.

- The networking module receives user information along with a file to print from the user application. It passes them to stream handler to generate the corresponding print stream. When the file format requires type conversion or indicates a web page link, this module tosses the data to the file handling module. Once the print stream is ready from the stream handling module, it delivers the stream to the smart device.

- The stream handling module is the core part of the CloudBridge daemon. Based on the printer information, it finds the matching driver in its database and generates the print stream with the options designated by the smart device user. Upon generation of the print stream, it makes decision on whether to compress the stream or not by applying a pre-trained decision functions based on the network bandwidth and the stream size. We further discuss about the compression decision functions in Section 5.

- The file handling module intervenes only when the daemon receives an advanced file format which cannot be directly interpreted by the driver. In such cases, it selects the corresponding file converter and converts the file into a basic format (e.g., PDF). Also when the file format is platform specific, i.e., only supported on Windows OS or Mac OS X, this module performs the conversion in the corresponding OS virtualized in the cloud server. The print quality is guaranteed after conversion as it borrows the format conversion ability from full-fledged applications on conventional computers. Applications not dedicated to a file format may also give the results but the details such as layout, styles,

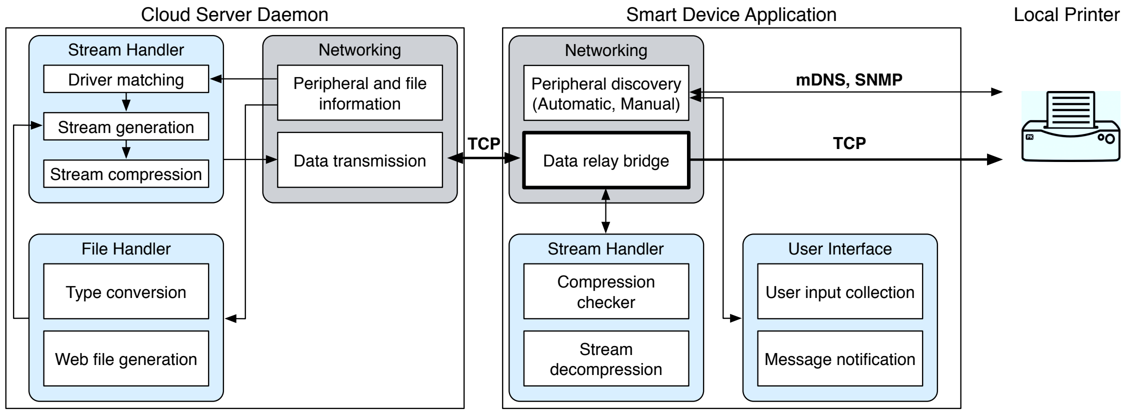


Figure 3: System architecture of CloudBridge.

and fonts are not comparable with the one utilized the genuine application. Once the conversion is done, the converted file is delivered to the stream handling module which generates the print stream subsequently.

4. SYSTEM VALIDATION AND ANALYSIS

In this section, we validate the feasibility of our system through extensive experiments using various Android smart devices (Samsung Galaxy S II, LG G2x, and HTC Evo Shift), two physical networked printers (HP LaserJet 4250, Brother 2270DW), a huge number of emulated printers from four major printer manufacturers, and a Linux server. According to a recent article [8] regarding the world printer market share as of 2011, the major manufacturers cover 80% of the market, i.e., HP 42.9%, Canon 18.1%, Epson 12.6%, and Samsung 5.7%. Motivated by this fact, we installed 680 HP, 131 Canon, 212 Epson, and 144 Samsung printer drivers, 1,167 in total, on the Linux server to gain the universality of the performance emulation results. For energy measurement, we use a Monsoon digital power meter [10] which can dump the power readings. The lowest reading interval 200 μs is used to get the most accurate measurement.

4.1 Operation Time Analysis

First, we evaluate the end-to-end operation time of the system. From the user's point of view, the operation time that she may go through using the system might be the most important performance metric. Analyzing time portion taken by different operations helps identify the performance bottleneck of the system. We split the total printing time into four time intervals as shown in Figure 2, and summarize them in Table 2.

Initialization time stands for the time taken transmitting the file and printer information from the user application to the server. File conversion time denotes the consumed converting an advanced file format to a basic one, triggering the type conversion module running on a virtualized Windows machine. Note that the file conversion time is optional for

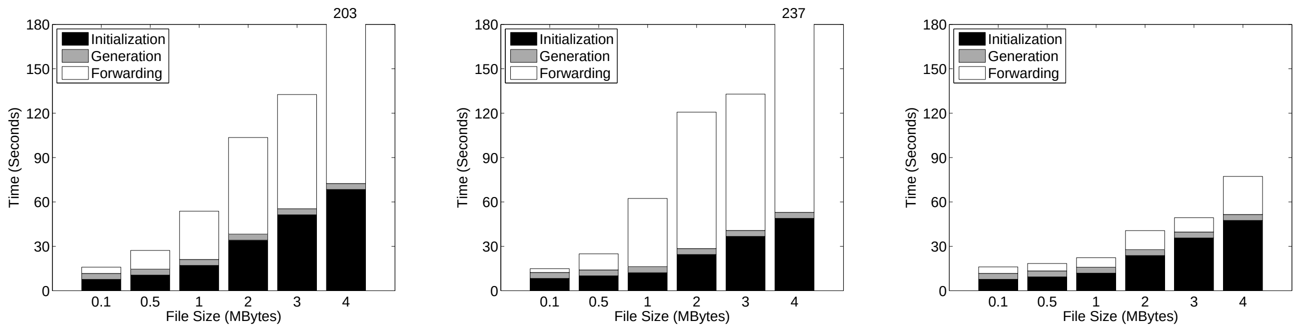
Time Intervals	Representation
Initialization Time	$t_2 - t_1$
File Conversion Time	$t_3 - t_2$
Stream Generation Time	$t_4 - t_3$
Stream Forwarding Time	$t_5 - t_4$
Total Print Time	$t_5 - t_1$

Table 2: Time intervals for sub-procedures indicated in Figure 2.

advanced formats. Stream generation time is measured from the moment when a print command is committed until the server finishes generating a complete print stream. Stream forwarding time starts when the first stream packet is sent by the server until the printer has received the last packet. We first present results using physical printers excluding compression technique, and then extend the experiment to over 1,000 printers for both cases with and without compression.

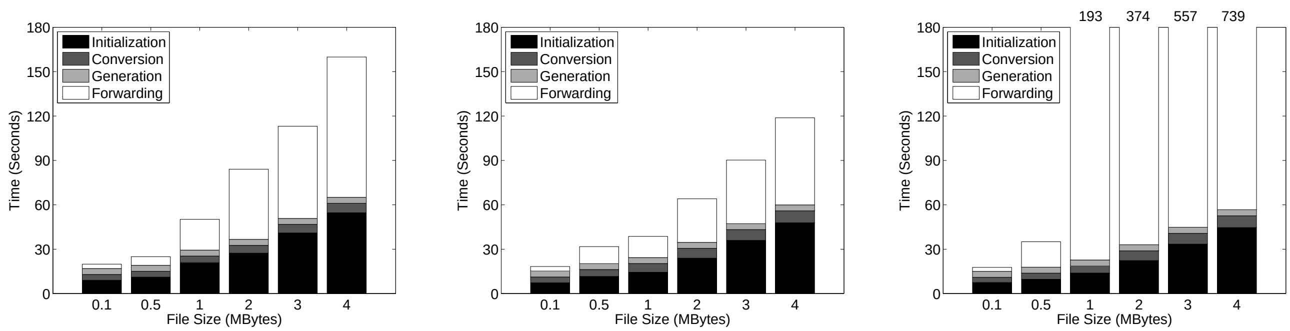
Figure 4 and 5 show the time distribution of sub-procedures measured for the basic and advanced formats, respectively. The initialization and forwarding time for both cases are linearly increasing along with the file size. This is intuitive as these two metrics are pure network transfer time which is highly dependent on the data size assuming the network condition remains stable. From the fact that the stream forwarding usually takes longer time than the initialization, we can infer that the print stream size becomes much larger than the original file in most cases. This finding motivates our approach to introduce the data compression, which is discussed in detail in Section 5.

An interesting observation is that the forwarding time tends to show high variation depending on the file format. The forwarding time of PPT file is longer than that of TXT file about 5 times in average. It is due to the embedded complexity of PPT format which usually contains a lot of graphical contents such as images, tables, and animation effects. On the other hand, the forwarding time of PS file is even less than its initialization time. Since PS file is already quite close to



(a) Text (TXT) (b) Portable Document Format (PDF) (c) PostScript (PS)

Figure 4: Time distribution of sub-procedures for basic file types. For text and PDF files, forwarding time is the bottleneck while initialization time is the most critical portion for PS file type.



(a) MS Word (DOC) (b) MS Excel (XLS) (c) MS PowerPoint (PPT)

Figure 5: Time distribution of sub-procedures for advanced file types. Stream forwarding time highly increases especially for PPT files as the file size increases, due to the complicated graphics.

the print stream format, the stream size turns out to be almost the same as the original file.

From the results, we conclude that the stream forwarding time dominantly determines the user experience on total printing time. As we pointed out previously, the forwarding time is affected by the generated stream size and the network condition. Next, we investigate which factors impact on the stream size.

4.2 Stream Size Analysis

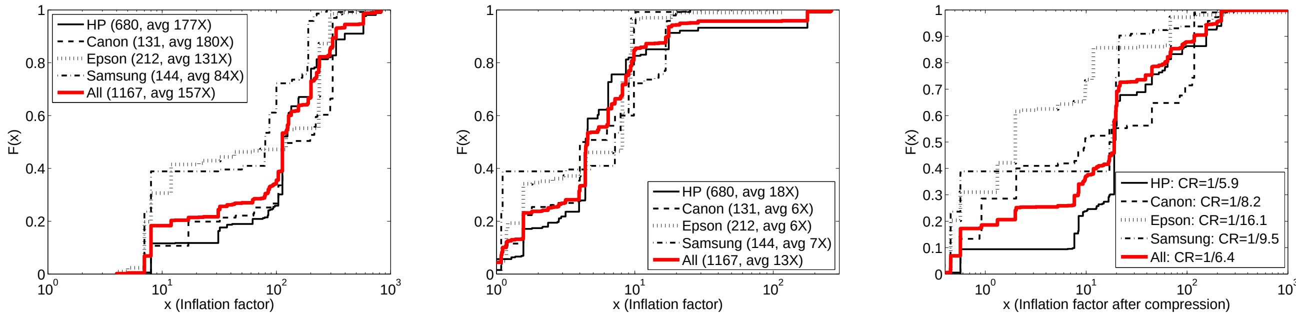
We define a term *inflation factor (IF)* as the ratio between the size of the generated print stream and the original file. We focus on two major factors determining IF value, file format and printer type, and quantify their impacts on IF values in various settings.

4.2.1 IF vs. File format

Continued from the experiment presented in Figure 4 and 5, we measure the correlation between the size of the generated stream and the original file for each format. We observe that TXT files give strong correlation coefficient of 0.99 while the average IF is around 10. This is intuitive since the TXT format is simple enough that the interpretation overhead may monotonically increase as the file size increases. PDF files give quite low correlation coefficient of 0.29 with average IF of 3. This is due to the fact that PDF format may contain many graphics which are not aligned, thus lead to various stream sizes that are unpredictable. The unpredictability of IF value increases when the file includes various type of contents other than texts. In other words, IF value shows diversity depending on the file format as well as the contents of the file itself.

4.2.2 IF vs. Printer type

To generalize the IF values for various printers, we emulate 1,167 printers whose drivers are installed in the cloud server. Figure 6 shows CDFs (cumulative distribution function) of IF values for various cases using printers from major manufacturers. From the results using 1 KB RFC TXT file as input illustrated in Figure 6(a), we observe that IF values are typically large. Only 20% of printers show IF values less than 10, while more than 40% show IF values larger than 100. We also verify that small IF values ($\sim 10\times$) mostly come from printers utilizing PCL6, since it adopts more compact commands than the previous versions. On the other hand, higher IF values ($\sim 100\times$ and over) result from devices using previous PCL versions (e.g., PCL5, 4,



(a) TXT file w/o compression (b) PS file w/o compression (c) TXT file w/ compression

Figure 6: CDFs of inflation factor for various cases. (a) IF for TXT file can be categorized into three groups: small(∼10×), medium(∼100×) and large(∼200, 300×) IF. 50% of the printers generate streams ∼100× larger than the original size. (b) The average IF for PS file is smaller than that of TXT. Over 80% of the printers generate streams less than ∼10× of the original size. (c) Reduced IF by applying the PPM compression to the same TXT file used in (a).

and lower). They are originally designed to convert a file into a raster image which expresses contents using bit sequences. The difference comes from the characteristics of the printer languages that the higher PCL version renders objects as vectors whereas the lower PCL version records the location of dots. However, one should note that the higher version of PCL not always guarantee low IF, according to a technical report from HP [7].

Figure 6(b) shows another experiment using PS format as input, which gives lower average IF values compare to TXT case. Over 80% of the printers generate print streams smaller than 10× of the original size. Based on our observation, print streams generated from PS files have low IF due to the nature of file format which relies on a printer-friendly language. This result accords closely to the previous observation shown in Figure 4(c).

5. SYSTEM OPTIMIZATION

Recall that our objective is to enable printing from smart devices, but the large IF values limit the practicality of the system. To further optimize the performance, we consider to apply compression to the print stream. However, selecting a compression technique is not straightforward. To identify a compression scheme that best fits the print stream, we first analyze the characteristics of the stream.

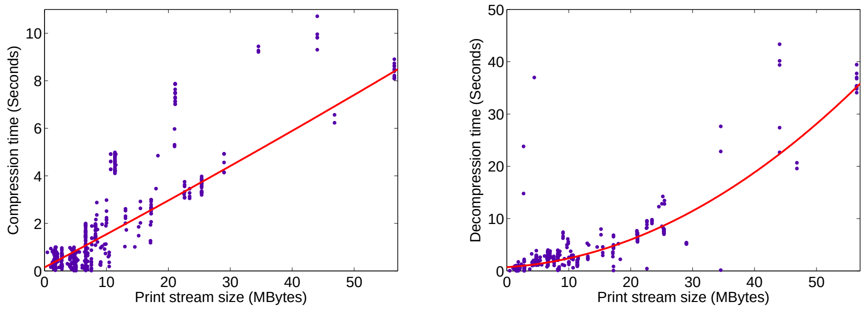
To begin with, we delve into the structure of the data compression. Most of the data compression algorithms consist of at least a model and a coder with optional preprocessing transforms when needed. A model estimates the probability distribution of the appearance of symbols in the inputs. Usually this is expressed as a sequence of predictions of successive symbols (e.g., bits, bytes, or words) in the input sequence given the previous input as context. When the compressor passes the prediction and symbol to the coder, it assigns shorter codes to the more likely symbols to minimize the output file size.

Among various lossless compression techniques in the literature, PAQ [17] is a series of open source data compression schemes that have top ranked on several benchmarks measuring compression ratio at the expense of compression speed and memory usage. Especially, the very slow compression speed is the representative drawback of PAQ, and this is due to its bitwise operation. PAQ uses a context mixing algorithm that predicts the next symbol using a weighed combination of probability estimates from a large number of models conditioned on different contexts, which contributes to the high compression ratio. PAQ utilizes several models such as picture (bitmap image), record (2-dimensional data), word (English text), and DMC (Dynamic Markov Compression) model. These models are given different weights depending on the relevance with input file types.

To verify which model can represent the characteristic of print stream, we analyze the weight proportion of every model utilized in PAQ for the print stream. The conclusion we get from the experiment is that in most cases DMC model is dominant and picture model follows the next. To reduce the compression overhead using PAQ, one alternative is to select some models that fit well for the print stream instead of applying all models supported by PAQ. Based on our findings, DMC model seems to be a good option.

Dynamic Markov Compression (DMC) [16] uses statistical model and predictive arithmetic coding. The predictor utilizes a table of variable length bit level contexts that map to a pair of counts n_0 and n_1. It predicts the next bit with probability $n_1/(n_0 + n_1)$ and updates by incrementing the corresponding count. DMC has a good compression ratio but requires large memory space and is not widely implemented. It predicts and codes one bit at a time similar to PAQ, which also results in slow compression speed.

Thus, we choose PPM (Prediction by Partial Matching) algorithm which can compensates the slow speed and memory requirement of DMC to the detriment of the compression ratio. It has a similar structure but differs from DMC in that it codes one byte at a time rather than a bit. It differs from



(a) Compression time (t_c) (b) Decompression time (t_d)

Figure 7: Measured operation time and their polynomial regression functions. For an arbitrary stream size x, a Linux server with Intel Quad-core i7 CPU gives $t_c = 1.45e^{-4}x^2 + 0.1379x + 0.1464$, and Samsung Galaxy S II shows $t_d = 9.51e^{-3}x^2 + 7.26e^{-2}x + 0.7218$.

Variable	Meaning
x	Generated print stream size (MB)
B_d	Downlink bandwidth (Mbps)
x_c	Compressed print stream size (MB)
t_c	Compression time on the server (second)
t_d	Decompression time on Android (second)

Table 3: Parameters and their units used in decision function modeling. We consider x and B_d as independent variables and model others using the independent variables.

context mixing utilized by PAQ in that there is only one context model per prediction. Additionally, PPM is theoretically proven to be optimal in the compression ratio [14,15,18,19]. Based on these learnings, we choose PPM algorithm.

Figure 6(c) presents the IF values for the same file used in Figure 6(a) after applying PPM compression. On average, we get a compression ratio of 10 which indicates that the stream size is reduced to 1/10. Beneficial from the high compression ratio, only 30% out of 1,167 printers have IF values of 20× or more after compression. Despite of the obvious benefit, compression of print stream could also degrade the performance since compression as well as decompression take time and the decompression on a smart device is computation-intensive operation leading to high energy consumption.

5.1 Decision Function Design

To determine whether to compress the stream or not, we design a decision function being operated at the cloud server. The decision function is designed to optimize user experience in terms of the total print time and the energy consumption on a smart device based on the parameters listed in Table 3. We model each of the parameters using a few independent variables and create decision criteria for the print time and the energy consumption.

We model the compression time t_c at a cloud server and the decompression time t_d at a smart device. Figure 7(a) and 7(b) show the measurements from 100 experimental runs with various files. They also render the best fitting regression equations of the results. We assume that the size of the compressed stream x_c becomes $0.5x$ on average. Note that the compression ratio becomes smaller than the ratio shown in Figure 6(c), because of the limited capability of a PPM library for Android smart devices. The compression ratios shown in Figure 6(c) can be considered as upper bound.

5.1.1 *Total print time*

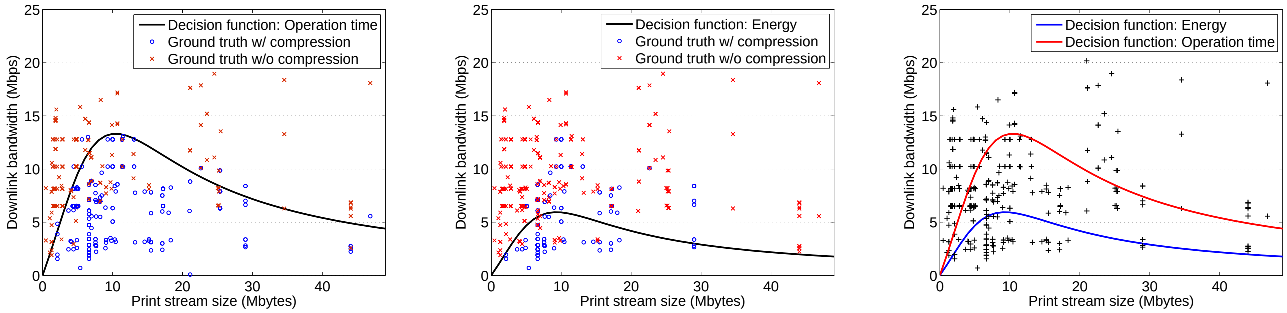
We form a decision function as Equation 1 based on the total operation time. The right side of the inequality inside the indicator function represents the time consumed when compression is applied, and the left side shows that without compression. Note that the time for common sub-procedures, e.g., initialization and stream generation, are not considered. We further simplify it by applying regression equations for t_c, t_d, and x_c, and get Equation 2. For a given stream size x, when the downlink bandwidth B_d is lower than the value of $0.5x/(0.020137x^2 - 0.11958x + 2.188)$, compression is recommended. This implies that when the downlink bandwidth is high enough, transmitting the print stream without compression benefits in time as it eliminates the compression and decompression time.

$$I\left(\frac{x}{B_d} > \frac{x_c}{B_d} + t_c + t_d\right) = \begin{cases} 1 & : \text{Compression} \\ 0 & : \text{No compression,} \end{cases} \quad (1)$$

where $I(\cdot)$ denotes for the indicator function.

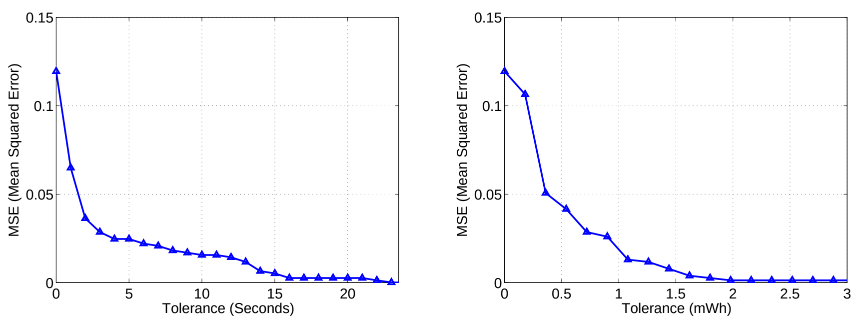
$$I\left(B_d < \frac{0.5x}{0.020137x^2 - 0.11958x + 2.188}\right) = \begin{cases} 1 & : \text{Compression} \\ 0 & : \text{No compression.} \end{cases} \quad (2)$$

The decision function and ground truth data from a large number of experimental runs are plotted in Figure 8(a). The mark ○ stands for the ground truth values where the compression gives shorter print time while × indicates the opposite



(a) End-to-end operation time (b) Energy consumption (c) Considering both

Figure 8: Decision functions based on (a) operation time only, (b) energy consumption only, and (c) both. (a)-(b) The mark ○ stands for the ground truth value which performs better using compression, and × indicates the case with no compression scheme. (c) The experiment set is divided into three groups according to the two decision functions.



(a) End-to-end operation time (b) Energy consumption

Figure 9: Mean squared error for the decision functions for two different criteria. (a) When users allow about 2 seconds of tolerance, the decision function gives over 95 % of accuracy. (b) If users can tolerate about 0.5 mWh of energy difference, the decision function makes only 4.1 % errors.

case. The ○ marks over the decision criteria line are considered as false negatives (FNs) and the × marks below the criteria are regarded as false positives (FPs).

For practical evaluation of the decision function, we define *tolerance* as a threshold value of the difference between the total print time with and without compression. We introduce this concept to mitigate the strictness determining FP and FN errors. For example, when the tolerance is 1 second, the ground truth data having less than 1 second of difference in total print time are not considered as error. Thus, 0 second of tolerance implies the conventional definition of FP and FN. Figure 9(a) shows the mean squared error (MSE) of our decision function for various tolerance values. When users allow 5 seconds of tolerance, it gives MSE of 0.024, meaning that the decision is correct for 97.6% of the trials.

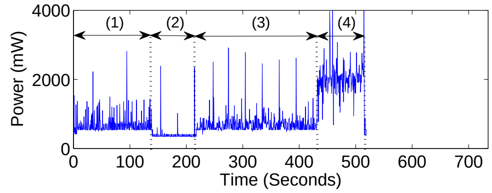
5.1.2 Energy consumption on Android

Here, we introduce another criterion in the decision function, the energy consumption on a smart device. Figure 10 illustrates power measurement when running the CloudBridge application on Samsung Galaxy S II for both cases, with and without compression. An interesting thing is that the energy consumption of decompression is about three time higher than that of data reception. In this case, applying compression may incur a great loss of energy compensating for short operation time. It is important to note that the power consumption values may vary for different models of smart devices as they use diverse processors and WiFi chipsets. Table 4 presents the average power level measured for three Android devices which shows diversity.

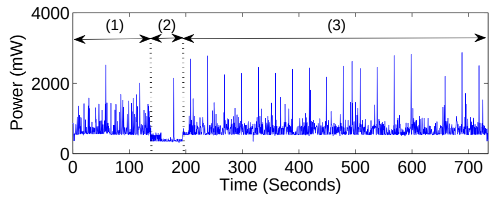
Device	P_i	P_r	P_d
Samsung Galaxy S II	415 mW	717 mW	2014 mW
LG G2x	315 mW	760 mW	963 mW
HTC Evo Shift	243 mW	574 mW	714 mW

Table 4: Average power level measured on three Android devices for idle state (P_i), data reception (P_r), and decompression (P_d).

By applying the average power consumption values to the operation time, a decision function considering the energy consumption is derived as Equation 3. It is simplified into



(a) With compression



(b) Without compression

Figure 10: Power consumption measured on the Android device, Samsung Galaxy S II. (a) Operation with compression is divided into 4 sequences: (1) file transmission, (2) idle, (3) stream reception, and (4) decompression. (b) Operation without compression takes longer time receiving the stream.

Equation 4, which determines compression depending on B_d and x.

$$I\left(\frac{x}{B_d}\int P_r(t)dt > \frac{x_c}{B_d}\int P_r(t)dt + t_c\int P_i(t)dt + t_d\int P_d(t)dt\right) = \begin{cases} 1 & : \text{Compression} \\ 0 & : \text{No compression.} \end{cases} \quad (3)$$

$$I\left(B_d < \frac{350x}{34.76596x^2 - 173.5292x + 2991.62}\right) = \begin{cases} 1 & : \text{Compression} \\ 0 & : \text{No compression.} \end{cases} \quad (4)$$

The decision function in Figure 8(b) suppresses compression compare to Figure 8(a), since the decompression on Android consumes higher energy than the data transfer. Figure 9(b) shows the MSE for various tolerance values represented in mWh. It implies that if a user can tolerate 0.5 mWh of energy difference, the decision function makes only 4.1% errors. Generally, 0.5 mWh corresponds to 0.01% of the total battery capacity of a typical smart phone (5000 mWh).

5.2 Decision Making

We discuss about the decision making considering both criteria at the same time. When overlapping the decision functions together as shown in Figure 8(c), it classifies the regions into three cases. When B_d and x fall into the cases included in the lowest or the highest region, the decision making becomes easy. Compression benefits by time and energy at the lowest region, whereas no compression benefits in the highest region. The region in the middle is equivocal: compression benefits from the total print time, but may give penalty in terms of energy. This is due to the nature of print stream which gives large variance depending on other variables such as file format, file size, and printer type. To improve the quality of experience for the equivocal cases, users may indicate her preference on time and energy.

6. CONCLUSION

In this paper, we propose a cloud-powered system, CloudBridge enabling peripheral support on smart devices. To prove the concept, we focus on printing from smart devices. CloudBridge is universally applicable to all smart devices and all networked printers and is completely independent from personal computers. More importantly, it also provides indistinguishable experiences (i.e., quality of printouts) to smart devices users from that of conventional computers.

For practicality, we adopt decision functions to our system, optimizing performance metrics closely related to user experiences such as total print time and energy consumption in smart devices. Through extensive measurements and training from the measurement data, the decision functions are shown to provide accurate decisions on whether to compress data or not with more than 95% of probability.

The CloudBridge system architecture relying on cloud servers for the intelligence of interpreting languages to communicate with peripherals has high flexibility and scalability by its nature. We expect our system architecture brings more practical solutions to smart devices helping such devices overcome functional limitations over conventional computers.

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