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What if ... Digital Cameras didn't need (local) Storage?

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Abstract—Cloud computing suggests that we can move computers from the desktop onto the network. In this article we investigate if we can do the same with digital imaging devices. After all, for most of us the practical management of local storage on digital cameras is a messy business, keeping track of all those SD cards and then figuring out which computer they are stored on. For most family units or socially organized groups the sensible end-point for a collection of images is on shared network storage where everyone can access and contribute to the image collection. So we consider (i) the current state of art in device connectivity; (ii) the current status of digital imaging devices and image/video data requirements; and (iii) we put together a proof of concept to test our hypothesis that cameras don't really need local storage any more and, yes, you could actually start to put your photographs directly into the clouds!

I. INTRODUCTION

Photography has recently passed through a major watershed with the recent and quite abrupt transition from film to digital cameras. This transition peaked in 2004 when film sales dropped by 36% in a single year. Even though the Eastman Kodak Corporation was one of the earliest pioneers of digital cameras, producing digital cameras from 1991, they were caught wrong-footed by the speed of this transition. This is the somewhat harsh reality of today's consumer electronics industry - disruptive change lurks around the corner.

Ironically, it was their global success in the film market that made this disruptive transition so difficult for Eastman Kodak - their success was based on the ease with which consumers could find film at almost any location on the planet and, after capturing their "Kodak momentsTM", they could get the same film developed and prints of the photographs mailed to their doorstep with equal ease. But digital cameras, removable memory cards and desktop PCs rapidly reached a critical mass that made the entire infrastructure for film obsolete. Within a few short years people were viewing pictures on their computer and sharing them by e-mail and film photography has rapidly faded into history.

In this article we consider if there may be another watershed ahead with the rapid growth of networking, both wired and wireless, and the increasing synergy between mobile communications devices and digital imaging technologies. How close are we to the day when our imaging devices won't require local storage any more? And what are the implications for camera and memory manufacturers?

II. PIECES OF THE TECHNOLOGY PUZZLE

We next take a look at different technology fields which are contributing to the infrastructure required to support a camera without storage:

A. Review of Camera Connectivity

Since the early 2000's, researchers have tried to find new ways to improve the connectivity of digital cameras [1]-[8] and reliably transfer pictures from the camera local storage to an end destination, with minimal involvement on the part of the user. Early work [6], [7] used a dial-up connection but this was soon superseded by Bluetooth [2] and cell-phone network [1] connectivity and then by wireless 802.11b [4]. Later, after the introduction of USB technology in digital cameras, the PTP [3] standard was created to take the full advantage of the increased transfer speeds implementing easy management of capturing and transfer operations.

Figures 1(a) & 1(b) show an early outline of two and three-tier network architectures for digital photography. The three-tier architecture is closer to today's *cloud computing* vision of software-as-a-service (SaaS).

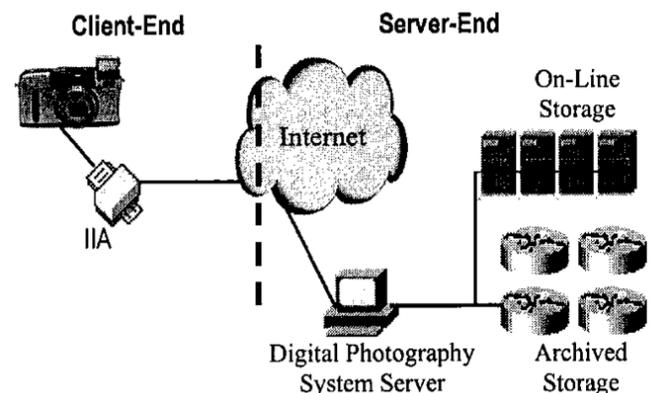


Figure 1(a): Two-tier network architecture for "Internet Photography" from [6].

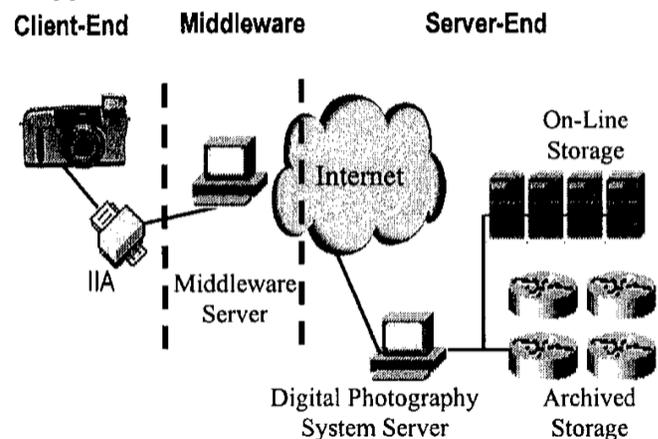


Figure 1(b): Three-tier network architecture for "Internet Photography" from [6].

Eventually, PTP was standardized using an underlying

TCP/IP transport over WLAN and LAN networks under the name of PTP/IP [5], [6]. Although not widely adopted for practical applications, PTP/IP does offer mechanisms to extend the device-to-device pairing of PTP over local or even wide-area networks without sacrificing the ease-of-use of PTP itself [6]. In other early work Corcoran and Raducan [4] looked at optimizing the transfer of MJPEG video over an 802.11b network, finding that three concurrent video streams could be supported.

B. Connectivity Enhanced Storage

Various approaches to connecting content capture devices to external network storage have been proposed and some products have appeared on the market. For existing digital still and video cameras some of these approaches have focused on the use of familiar flash card formats to combine a local storage capability with a network off-load capability.

The basic idea for these devices is that photographs and video content is captured on the local digital storage in the card, which also contains a WiFi radio that allows the content on the card storage to be transferred automatically through the network to a network storage device in the local (home) wireless network. Some examples of these products are the Eye-Fi™ and Trek FluCard™ shown in Figure 2.

These devices are shown in Figure xx. Since SD flash memory cards are the most popular camera card format both the Eye-Fi™ and FluCard™ are available in this format.

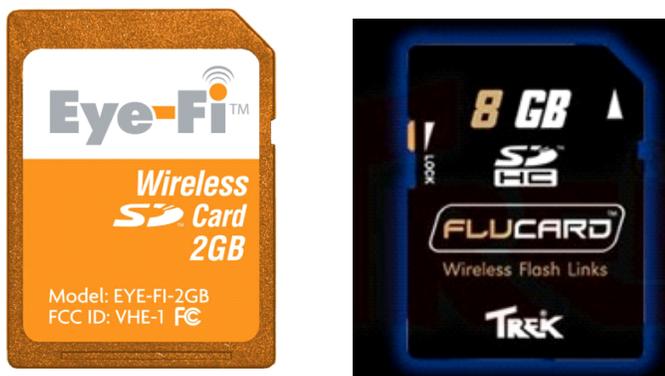


Figure 2: Combination Flash Memory and Wireless Network Cards for Automatic Transfer of Content to Network Storage.

These devices can provide a way to automatically sweep content from the card to the network. Usually a local network storage device is the target for this transfer as this generally allows faster data rates than storage in the Internet and is available even when Internet connectivity is not. However moving the content through the Internet to a cloud storage service or to a personal cloud (more on this later) is another option.

There are disadvantages to providing automatic content transfer over a local network that is not part of the underlying camera architecture. Since the camera doesn't know that the

wireless card is transferring data it may shut down the camera (and thus the power on the card) while the card is still transporting images or video. Also if the WiFi enabled card is not being used in the camera the data will not be transferred to the local network storage.

An interesting alternative to the home Network Attached Storage (NAS) device is to have the camera upload content to a mobile wireless NAS device. This allows the user to use either camera or card based WiFi content transfer to be used for transfer of content to a local mobile battery powered NAS device. Seagate and Kingston products with mobile WiFi access are shown in Figure 3.



Figure 3: Personal Cloud Storage Devices.

Whatever the means of transferring the pictures from the camera to a local network storage, once this content is transferred it can be uploaded to other storage networks e.g. a personal cloud device can be copied to a home NAS storage system. The content or some part of it can also be uploaded to storage services in the Internet and shared with others - probably in your trusted network - through content sharing services (such as Facebook™, Picassa™ or Fliker™) on the Internet or in a cloud storage service.

Another option is to have a local network storage device that is the initial target for the automatic content transfer itself be accessible through the Internet. Web sharing from a network storage device in the home has been possible for many years by more experienced computer technicians and value added resellers and system integrators for the more upscale consumer market.

Products that allow a local network storage device to serve as an Internet accessible device have been on the market for a while. These are basically NAS devices that are also accessible through the internet through an URL. These devices introduced by many major home NAS providers such as HP, Seagate, Western Digital and others often used an external web site as the authentication site that supported the access URL that would then direct a client to the home NAS device. These services would often charge some annual fee to maintain access through the URL to the home NAS storage.

More recently home NAS devices have become available that allow more direct access to the NAS without this level of external authentication from a connected client. Some of the products offering these sort of home "Cloud Storage" are shown in Figure 4.



Figure 4: Home Cloud Storage Devices.

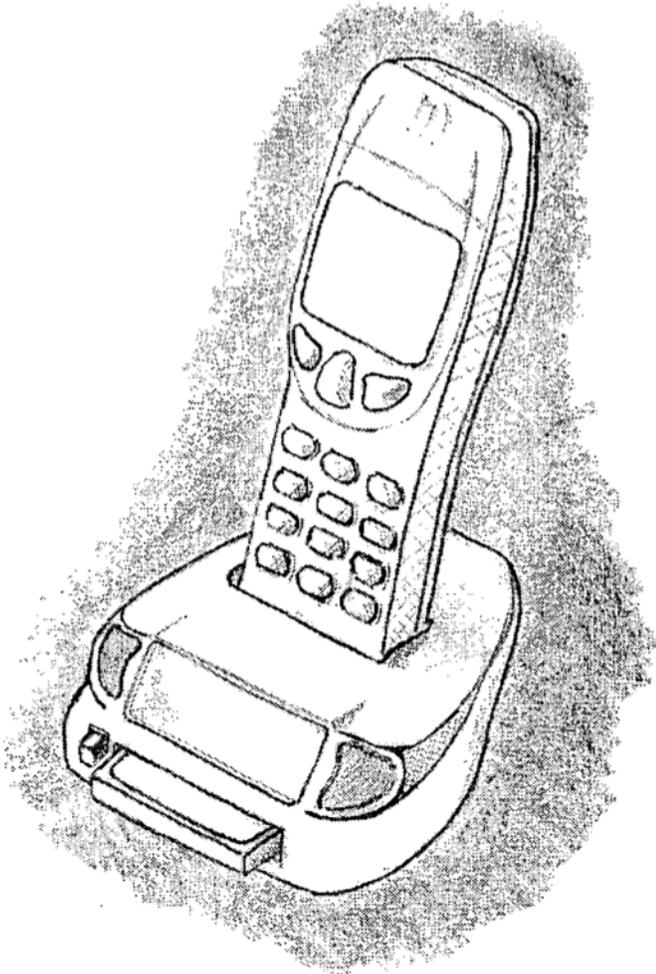


Figure 5: Artist's impression of a network upload-cradle for a mobile phone or memory card from [1]; a pre-cursor of more modern devices such as the EyeFi™.

C. The Rapid Growth of Networks

One of the most comprehensive sources for detailed information on global networks can be found at [10]. The conclusions are fascinating and worthy of an article on their own but here we consider only the projection which are most pertinent to our current hypothesis.

Overall, network traffic is expected to grow at a compound growth rate (CAGR) of 32% from 2010 to 2015. By 2015 the gigabyte equivalent of *all movies ever made* will cross global IP networks *every 5 minutes*. A large part of the growth is in

video traffic which is currently 40% of all traffic and will rise to 62% by 2015 and these figures do not include P2P video sharing. In fact by 2015 if we sum all forms of video - IPTV, VoD, Internet and P2P - they will account for 90% of global consumer traffic by 2015. This strong growth in video will further drive network infrastructure and network capacity.

Traffic from wireless devices will exceed that from wired devices by 2015. IP traffic in North America, Europe and Asia will all reach or surpass 20 exabytes per month by 2015 and mobile data traffic will grow at a CAGR of 92% over this period [10]. By 2015 there will be over 6 million households worldwide generating more than 1TB of outgoing traffic - up from several hundred thousand in 2010. The number of devices connected to networks will be double the global population and non PC devices such as TVs, tablets and smartphones will grow with CAGR from 100% (TVs) to 216% (tablets).

Whew! Enough statistics. So what does all this mean? Well for starters our networks are growing at a phenomenal rate as are the numbers of devices connected to them. If we step back a little this suggests a completely new global infrastructure is emerging: more than the Internet we know and love; more than simple websites and online shopping; much, much more.

What we are seeing is the emergence of a new infrastructure for next generation consumer products and services; a powerful and robust infrastructure, driven primarily by the increased bandwidth requirements of live video streaming. And interestingly it is at the periphery - the wireless connectivity - where this infrastructure is growing at its fastest with a conservatively estimated CAGR of 92%.

In the context of the present discussion this new infrastructure provides a potentially disruptive technology shift for consumer cameras.

D. The Rise of Cloud Computing

Naturally storage won't go away, or perhaps we should say that it will go away - quite a distance from the device! Most likely it will end up on a "cloud" somewhere out on the network.

There is nothing very new here although arguably the introduction of new technologies such as virtual machines have enabled a more purist implementation of software and applications as services. Back in 2001 several of your authors worked in quite a large a start-up company where the business model was to store people's photographs on the Internet, generating revenue by printing and framing your pictures, and also offering services to personalize mugs and T-shirts with your images. Of course the Internet was a different place and I recall that 1 terabyte of network storage cost \$1,000,000. So putting pictures on-line was an expensive business in those early days. Fortunately today it is more cost-effective for companies and thus the consumer already has a range of cloud-based services available for storing pictures from major corporations such as Apple, Google and Yahoo.

The rate of growth and investment in Cloud Computing is also growing quite rapidly. In a companion article in this issue

this phenomenon is examined in some detail and the interested reader is referred here [11].

III. REQUIREMENTS ANALYSIS

A. The User Experience

Probably the greatest inconvenience of digital cameras is keeping track of memory cards. Typically images can be uploaded from the camera to a PC, or a new memory card can be inserted and the old card read, again into a computer. Some cameras feature a dedicated network cradle that will offload pictures after the camera is placed in the cradle. Of course all of these methodologies complicate the use of the camera, as the user has to manage memory cards, cables and cradles. If you own a digital camera, and who doesn't these days, you'll be familiar with at least one of these unduly complex user environments.

In an ideal world consumers would upload and sort their images regularly on a local PC, but this is rarely what happens in practice. Our busy lives mean that we shoot pictures until our memory cards are full, and then buy another memory card because its so cheap and we don't have time to sort all those images. The camera is often one of the last items to get packed when going on vacation and my own desk is littered with a handful of SD and SDHC memory cards from a handful of different cameras & video capture devices. So these all go in with the camera and, typically I spend a chunk of my vacation sorting all of the last year's pictures.

In *Figure 6* we illustrate three different user experience: (i) using memory cards; (ii) using PTP connectivity to simplify USB upload of images and (iii) using wireless PTP/IP which removes the need for a cable. Note that even though PTP and PTP/IP offer some improvements over the use of memory cards there is still some effort required by the user to initiate the offload of images. Our question is why the consumer should even have to think about this? What can't those images find their own way to a pre-determined location and ideally be sorted and categorized automatically?

B. Connectivity and Bandwidth

Well the answer is that all these things are in fact quite possible. The major barrier to date has been the difficulty in providing an easy to use *connectivity solution* with good availability to link the camera to the network. Ironically it has taken the emergence of a new category of device - smartphones & tablet - to break down this barrier. Now users are familiar with linking these devices to their wireless router so adding an imaging device (or using one of these devices as your imaging device!) has become more of an everyday occurrence for many consumers.

It would also be a reasonable comment that the network speed and the range of WiFi technology has improved significantly since earlier work [9]. Today most wireless routers are either enhanced 802.11g or better still 802.11n. Typically a single access point covers a normal single-family

home. Sustained throughput rates of 60-80 Mbps¹ or higher can be achieved with 802.11n technology.

However we need these high throughput rates. Lets consider a typical 12 Megapixel raw image; by the time it is compressed into a JPEG it is reduced to 4 MB in size. At a data rate of 10 Mbps this image would take about 3.5 seconds to transfer off the camera. As most cameras have a "click-through" time of about 1-2 seconds this is actually not fast enough and so we can estimate a minimum bandwidth requirement of about 20 Mbps for still images to complete image transfer within our 2 sec time window, or close to 40 Mbps for a 1 sec transfer.

For video we are more concerned with sustained throughput rates, rather than the bursty transfers for still images. For good quality SD video a bit-rate of 8 Mbps is needed, and for HD video (720p) bit-rates of 16 Mbps are essential.

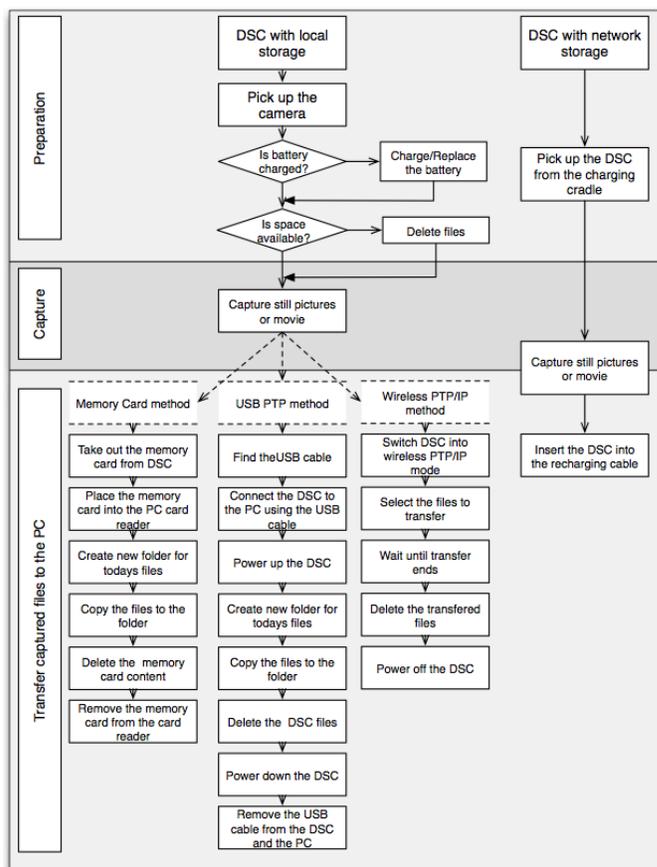


Figure 6: Capture experience for different DSC file transfer workflows. **Improve appearance of diagram (shorten text in over-full boxes)**

IV. PROOF OF CONCEPT.

The key question we want to investigate in this paper is if it is now practical, at least in a home WiFi network, to eliminate the local storage step of managing pictures from a camera. In other words, all pictures or video clips will be instantly transferred to a local storage directory. The user does not have

¹ This is the practical data transfer rate in most home environments. While higher rates may be quoted they are rarely achieved in practice and certainly not at some distance from the router.

to think about this, and there is not storage card to confuse the user. Our tests [9] indicate that a 32 MB cache is sufficient even for live video capture at 720p HD provided you have an 802.11n connection. A slightly larger cache would be needed for lower bandwidth connections.

Note that you will have to sort these out later, but at least every image and video clip you shoot in the home environment goes instantly to a long-term storage folder. In fact most modern image management solutions are very good at tagging and interpreting image metadata so this part of the system should be reasonably straightforward.

A. Improved User Experience

Our improved capture experience is illustrated in the right-most column of *Figure 4* above. You'll note how much easier this is than using memory cards, cables or wireless cradles. And by building WiFi into the camera the expectation is that it could work outside your home. But for the purposes of this paper we confine ourselves to the home network scenario.

B. System Overview

The test system comprises three main modules shown in *Figure 7* below. Each of these must be modified to enable the overall system, although many of the modifications are relatively trivial. In this short abstract we focus on the main modifications to the camera and storage systems.

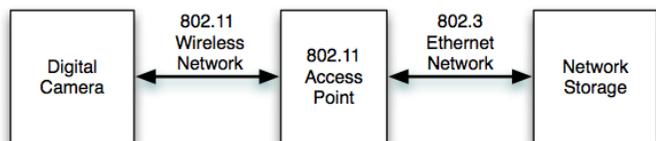


Figure 7: Overview System Model

C. System Layers

A layered view of system components that may be used to reach the virtual storage from the digital camera is presented in *Figure 8*. The access-point sits between digital camera and network storage. The camera is paired with the storage that is connected by Ethernet to the access point to avoid transmitting each image packet two-times over the wireless network.

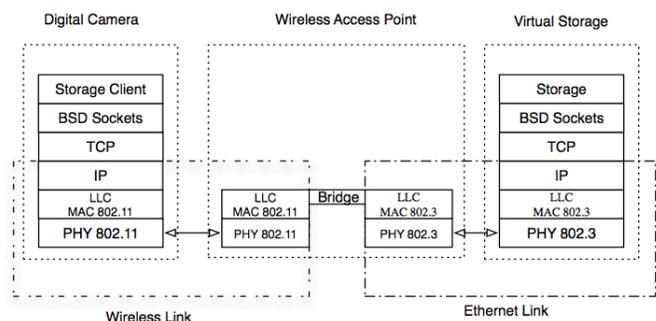


Figure 8: Virtual Storage for Digital Cameras: System Layers

D. Digital Camera Architecture

The DSC architecture requires the most significant changes as illustrated in *Figure 9*.

Firstly, several software components within the camera are modified to allow control of the quantity of data produced: video bit-rate or the interval between successive image capture events for still image capture. Thus the video recording subsystem is replaced by a *Video Data Producer* and still image capture is replaced by the *Still Data Producer* software module.

Secondly, a number of software subsystems are added to the digital camera. These subsystems forward data in a controlled manner from the data producer to the network storage. Most importantly, the *RAM buffer* accumulates data at production rate(s). Data is removed from *RAM buffer* by the *Network Storage Client* module. Data removal rate varies with the wireless network conditions. *Control Module* monitors the utilization of *RAM buffer*, the utilization of the TCP buffers and the wireless link speed. Based on the monitoring of these three subsystems, *Control Module* adjusts the data production rate(s) of the video and still image subsystems.

Thirdly, hardware and software subsystems are added to the DSC platform to enable the actual data transfer. These are the TCP/IP stack, the wireless network cards, and the wireless network card driver.

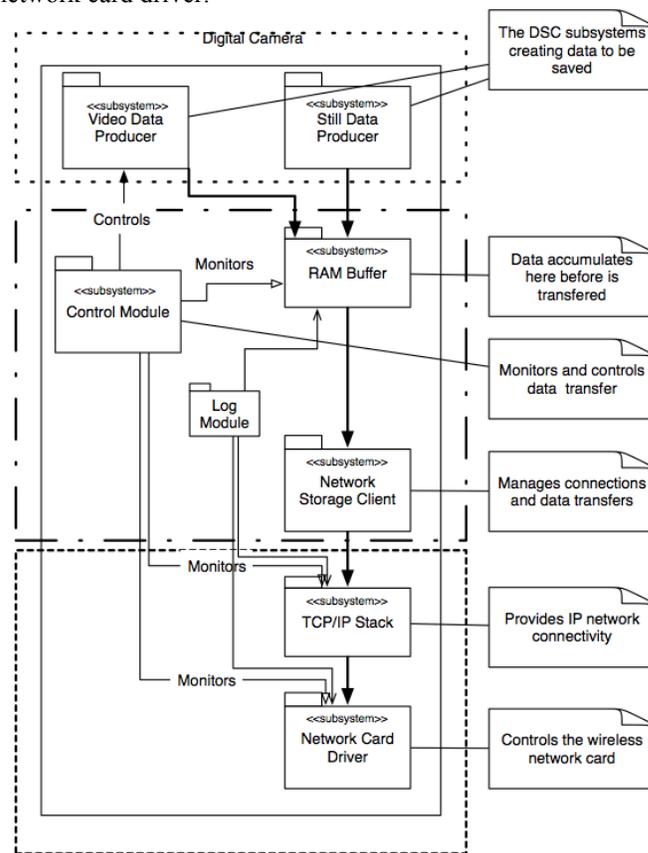


Figure 9: Required Changes to Standard Digital Camera Architecture

V. EXAMPLE TEST RESULTS

Here we can only present a small sub-set of our test results. The following examples give some idea of the more detailed testing program to investigate multiple combinations of still and video cameras operating concurrently. The tests detailed

below were measured using 12 Megapixel JPEG images for the still image transfers and standard definition VGA (SD) and 720p resolution video clips were used to test movie capture.

A. Test Environment

The diagram of the house and garden where the experiments were performed is presented in *Figure 10*. The distance from the wireless router varied from 6 feet (at point 2) to 60 feet (at point 7). The typical file size of pictures used in our experiments was 4 MB. This size is in line with image sizes of 12–14 raw megapixel captured with modern consumer cameras. Recorded movies had a bit-rate of 8 Mbps for SD quality and 16 MBps for HD quality. These bit-rates include both audio and video content.

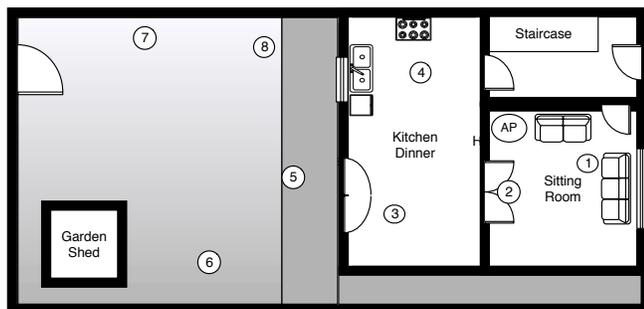


Figure 10: Layout of test-point locations referred to in test descriptions below; the house is a typical 3-bed room property with concrete walls.

The experiments were performed using both IEEE 802.11g and IEEE 802.11n wireless networks. A number of parameters were logged and later analyzed. The *RAM Buffer* is a large circular buffer controlled by the application layer. Data not yet sent to network storage accumulates in this buffer.

The *Socket Buffer* is the buffer associated with each network socket, under control of the TCP/IP stack. The application only controls writing to it, using BSD socket API functions. Socket buffer occupancy is an important variable in throughput computation.

Link Speed is the wireless card transmission speed. Throughput is computed from the RAM Buffer occupancy, socket buffer occupancy and data produced during an interval. Data produced varies when recording movies when the bit-rate control module changes the movie bit-rate.

B. Capturing Images with a single still Camera

Generally, still pictures were captured and transferred without problems at a rate of a picture each 2 seconds. This capture rate is perfectly acceptable for a low-end digital camera.

A typical plot of a normal still picture transfer for an 802.11g network is depicted in *Figure 11(a)*. Fifteen consecutive pictures were captured at approximately 2 seconds intervals. All pictures were transferred at point 3 inside the house. Typically, the socket buffer remains fully occupied until the whole picture is transferred. During data transfer, data throughput peaks at a value limited by conditions on the

wireless network. Intervals of maximum data throughput are followed by intervals with no data transfer.

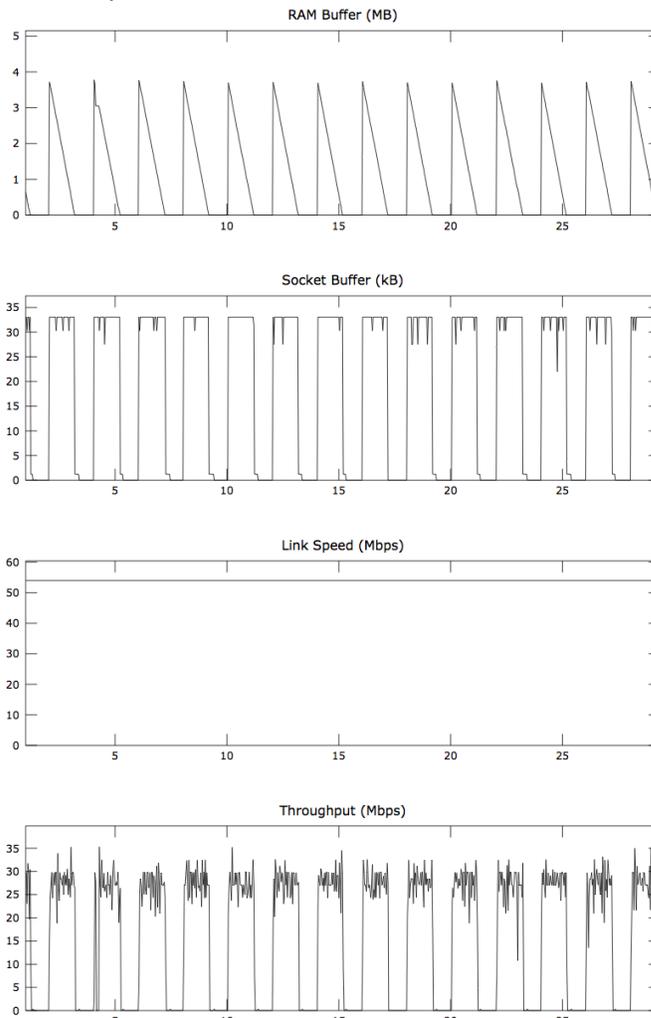


Figure 11(a): A normal sequence of still picture transfers at test point 3 with time interval of c. 2 seconds required per image transfer - 802.11g network.

Data transfer is slower further away from the AP. For example, *Figure 11(b)*, which depicts picture data transfer at point 8, shows what happens when the available bandwidth is not sufficient to match the image acquisition rate. In this example average network throughput is reduced to c.10 Mb/s. This value is lower than the 16 Mb/s value required for transferring an entire image in two seconds. Here we see data accumulation in the RAM buffer until the image acquisition rate drops.

Here our 15 images increase the RAM buffer utilization to 25 MB and the socket buffer is operating at 100% capacity for practically the entire image acquisition period. Only when we stop taking pictures will these buffers offload their image data. In a practical device a simple alarm beep could indicate buffer saturation to the user, indicating that he needs to slow down the speed at which he is taking pictures.

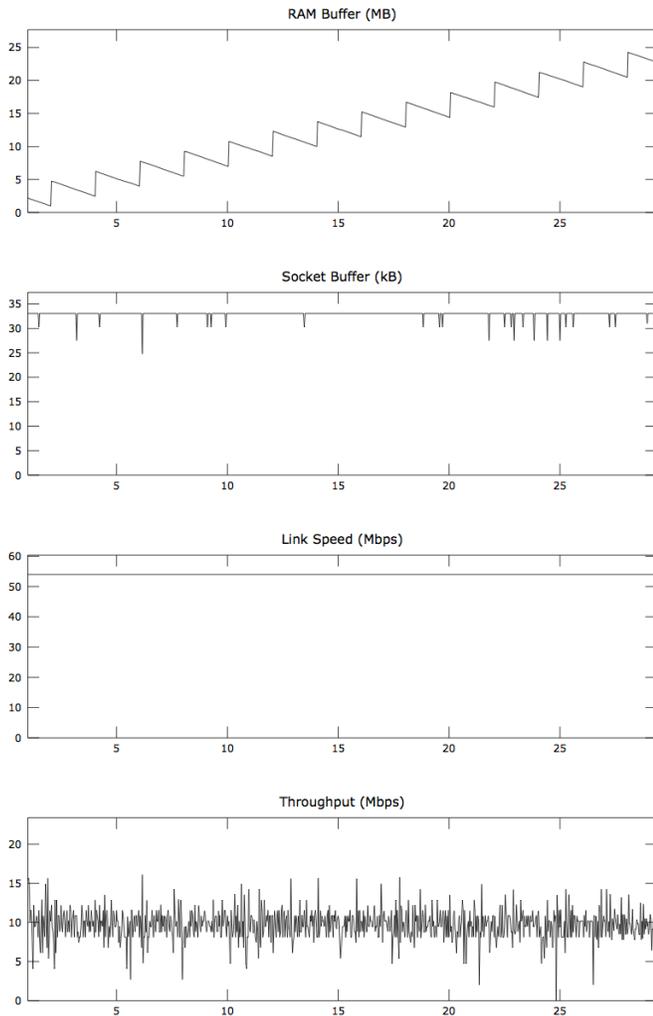


Figure 11(b): A corresponding sequence of still picture transfers at test point 8 with time interval of c. 2 seconds when network bandwidth is not sufficient to fully offload each acquired image - 802.11g network.

As might be expected the general characteristics of wireless-N networks are preferable to those of wireless-G for our proposed application scenario. The RAM Buffer was never completely filled during these experiments. However in a larger house, or commercial area there will be gaps in network coverage. There may also be multiple cameras sharing network bandwidth. Our next series of experiments focuses on video capture.

C. One DSC Recording Movies

For SD video the data transfer was always smooth, even when using an 802.11g router, averaging close to the data production rate. The RAM Buffer occupancy was low. Only on rare occasions did the transfer throughput drop below the data production rate. In our tests the RAM Buffer occupancy limit of 4 MB was not crossed. And so, even in a garden location where network performance is degraded, standard video can be handled by the system without any reduction in video quality.

For HD video on an 802.11g network, Figure 11 shows a test sequence recorded at garden test point 7. In this case network throughput is more variable and the RAM buffer fills

beyond the 4MB threshold causing the video production rate to be scaled back accordingly (bottom graph). This architectural modification to the video processing engine is required for such a wireless video device. Otherwise the RAM buffer will continue to fill until the camera begins to skip full frames of video. By gracefully degrading video quality we maintain the recording speed until network performance recovers and throughput rises to c. 25 Mbps, clearing the data backlog. For 802.11n no significant build-up of data in the RAM buffer occurred during our tests.

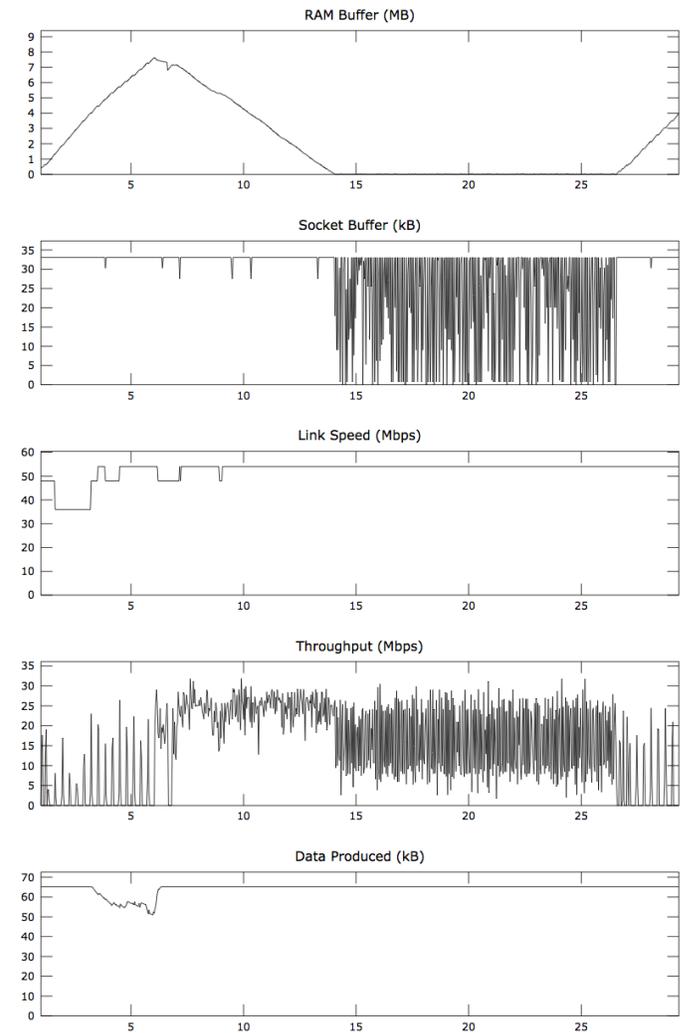


Figure 12: A high resolution video (720p) is captured and transferred over 802.11g network; in this case the RAM buffer threshold of 4MB is exceeded so the production bit-rate of the video is scaled back (bottom graph) but for less than a couple of minutes. Video quality might be slightly affected but only marginally and as soon as the RAM buffer drops below the 4MB threshold normal video production rates are resumed.

D. Simultaneous Image and Video Recording - two DSCs

These tests were performed on an IEEE 802.11n wireless network and proved uneventful. Recording SD or HD movies on one DSC at the same time as capturing pictures every 2 seconds with a second DSC did not cause any problems. Even when the slower IEEE 802.11g wireless network was used and movie recorded were of SD quality, the transfers took place without any significant reduction in image or video quality. A

number of short intervals were observed when data throughput was lower. In such cases the bit-rate control module performed well.

A more challenging combination proved to be recording HD movies with one DSC while capturing pictures with a second DSC in an 802.11g network. *Figures 12(a) & (b)* illustrate one such data transfer. Pictures were captured at test point 2 every 2 seconds - *Figure 12(a)*. This occupied a large amount of the overall bandwidth available as can be seen from the lower throughput graph. At the same time, movies were recording at point 7, at the back of the garden. The distance increase caused a throughput reduction. This reduction resulted in the intervention of the bit-rate control module. This intervention can be observed in the "Data Produced" plot at the bottom of *Figure 12(b)*.

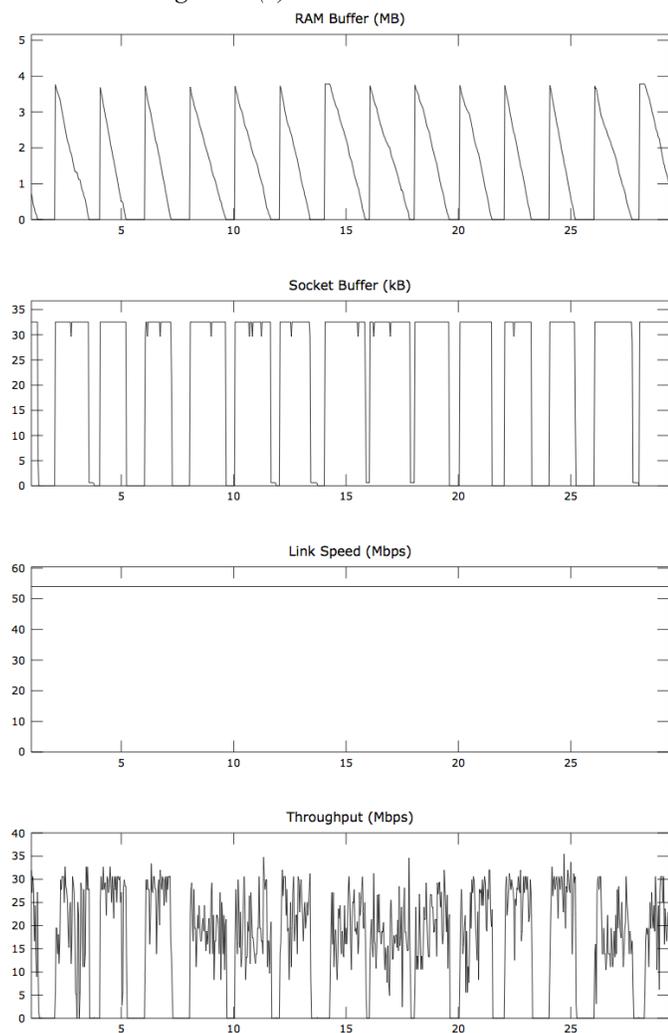


Figure 13(a): Test point 2 the first DSC acquires images at normal rates - one new image is acquired every 2 seconds.

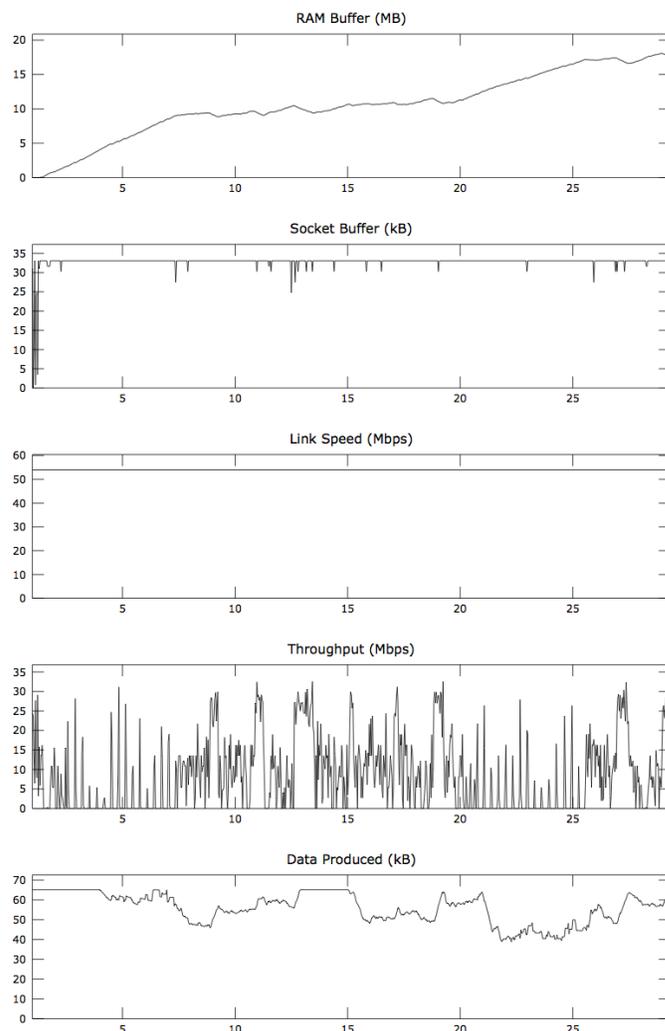


Figure 13(b): HD movies is recorded at test point 7 at the same time as the image acquisition of Figure 12(a); note that data production rates have to drop by as much as one third to accommodate the reduced availability of network bandwidth; the RAM buffer heads towards 25 MB.

VI. CONCLUSIONS & PROPOSALS FOR FUTURE WORK

Well it would seem that our initial "What-if?" question has got a pretty affirmative answer!

Our original hypothesis was that a camera should be able to operate without local storage over a home WiFi network. Our tests would seem to indicate that this is not only possible, but that over fairly typical wireless networks it can work very effectively. It would certainly be practical to shoot up to HD video in most home environments. A local memory cache would, of course, be needed but our tests show that a small 32 MB cache would be quite effective and anything larger would be a bonus.

Yes, we will need to modify the architectures of existing cameras to accommodate this, and yes, we've also seen that it is desirable that latest generation 802.11n networking technology is used. It is also true that we did not test with more than two cameras operating simultaneously, but these are issues that can be dealt through robust systems design.

What is clear is that as network technology continues to

improve and as improved imaging subsystems find their way onto our smart-phones the era of cloud-connected photography is within our grasp. It is no longer a matter of "What If?"; the question has been transformed by our proof-of-concept study and what we now need to ask is "How Soon?".

And I believe it may be sooner than you think!

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