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Term Paper Assignment

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Energy Management in Mobile Devices

Smart devices like smartphones, tablets, ipads are emerging with impressive functionality like gesture recognition, voice recognition, data transfer. Various kind of sensors like image sensors, voice sensors enable them to think critically and advance the artificial intelligence. Main concern for these devices is the energy consumption. Battery is drained excessively due to background activities like email syncing, continuous network management, GPS sensing and many more. Hence researchers are trying to optimize this energy consumption. This study comprises of such researches done in following topics:

1. Optimal configuration for energy efficient functioning of inbuilt camera
2. Hotword detection using AccelWord(eg: Siri and OK Google)
3. Optimization techniques for Location Sensing(eg:CAPS, aLoc)
4. Network traffic management

We show some configural changes and some hardware replacement for minimal energy usage. We also show the experimental analytics in each case how the energy usage can be dropped up to 50-70%.

INTRODUCTION

The cutting-edge technological advancement in mobile system's application has changed the way of living life. The time consuming and physically tiring activities are now possible with few touches. Let it be making reservations, banking, sending messages, or multimedia sharing, streaming media and tracing the location of your lost device or even your loved ones, apps developed these days made these things possible. These applications have increased the usage of smart devices on the large scale. The ease of these features comes with an overhead of a large amount of energy consumption. Statistics show that an average cell phone consumes 3.8 kWh energy annually. With an increasing number of devices, the energy consumption is the necessity of an hour.

Here in this study, we have analysed various studies done in the areas of smart device's application where most of the energy is consumed. We have targeted applications from the network, location sensing, continuous vision and hotword recognition. For example for location sensing, we provide an alternative technique, Aloc which compromises the accuracy for energy consumption. Another framework used for location sensing comprises of four major principles: substitution, suppression, piggy-backing, adaption sensing. Catnap is another technique based on Network based traffic management which provides meaningful sleep in the gaps of the package during transfer.

OPTIMIZATION IN IMAGE SENSING TOWARDS CONTINUOUS VISION (CAMERA)

We are aware of the fact that camera is one of the most power-hungry application, an alternative of using optimal clock frequency for various modes like photo and video, along with the accurate configuration of time for which image sensor is exposed to light can reduce a considerable amount of energy. We have also studied the alternative for microphone based audio detection technique with an audio sensor,accelerometer, for voice control application like Apple's 'Siri' and 'OK Google'. This technique not only saves the energy but combats with a variety of problems like user's mobility.

Smart devices come equipped with cameras. Let it be mobile phones, google project glass, laptops, tablets and smartphones. Conventional use of cameras have provoked many developers to come up with applications based on mobile computer vision, including barcode/QR code scanning, gesture-based interaction, and image recognition. But image sensing, the prime necessity of such kind of applications needs high power supply. More and more researchers are working to develop system with less battery consumption. In this section we will see some techniques to conserve energy in image sensing. We will try to analyse following relations (i) Relation between the power utilization by image sensors and its quality defining parameters(resolution and framerate) (ii) Energy efficient system perspective (iii) Image sensor hardware modifications for less energy utilization.

Hardware components related to image sensors:

Typical image sensor looks like as shown in the diagram above. Now let us see the prime functionality of each component

The pixel array: It contains array of pixel and transistors,where pixels act as photodetector and transistors change light into charge.

The analog signal chain: Analog- to- Digital-Converters (ADC). It gives digital output from the voltage of capacitor.

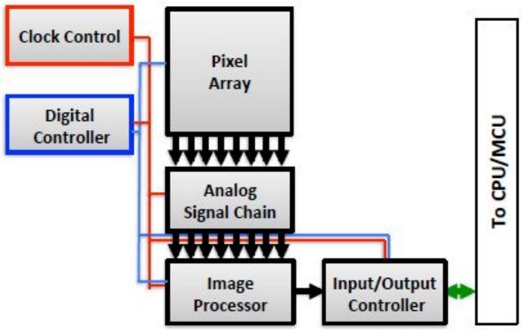


Figure 1: Architecture of the Image Sensor

The image processor: digital image processing example: demosaicking, white-balancing and denoising.

The I/O controller: It connects external world (processor -> image sensor) This component is used to set operational mode by sending instructions and parameters to determine resolution and frame rate.

The digital controller This component of image sensor is responsible for timely execution.

Equipment and Image Sensor

For this comparison National Instruments USB-621216-Bit,400 kilo sample/sec DAQ device for power measurements were used. Image sensors from major vendors are listed side. We

	Max. Res.	P_{active}	P_{idle}	Market
A1	2592x1944	163.5 mW	161.9 mW	Snapshot
A2	768x506	189.5 mW	141.8 mW	Automotive
B1	3264x2448	338.6 mW	225.4 mW	Mobile
B2	2592x1944	225.1 mW	218.6 mW	Mobile
B3	752x480	137.1 mW	105.9 mW	Security

Table 1: Characterization of Image Sensors and the Consumption of Power at 24MHz

can observe 15% to 45% reduction in analog power for sensors A2, B1 and B3. But conversely analog components reduce power merely, 1% or less. Whereas the drop is 10 to 55% for all of them and A1 & B2 show 3% of reduction. The I/O power reduction of 8% is observed by A1 and 40% by B2.

Symbol	Description	Model (Source)
R	Framerate	
N	Number of pixels in a frame	
f	Clock frequency	
T_{frame}	Frame time	$T_{frame} = 1/R$
T_{active}	Time in active state	$T_{active} \approx N/f$
T_{idle}	Time in idle state	$T_{idle} = T_{frame} - T_{active}$
P_{idle}	Power consumption in idle state	$P_{idle} = a_1 \cdot f + a_2$ (Equation 10)
P_{active}	Power consumption in active state	$P_{active} = (b_1 \cdot N + b_2) \cdot f + b_3$ (Equation 12)
E_{frame}	Energy per frame	$E_{frame} = P_{idle}T_{idle} + P_{active}T_{active}$ (Equation 1)
P_{seq}	Power consumption for sequential frame capturing	$P_{seq} = \frac{P_{idle} \cdot (T_{frame} - T_{active}) + P_{active} \cdot T_{active}}{T_{frame}}$ (Equation 4)

Table 2: Important Notations

Image sensor's energy consumption are not proportional to frame rate. Image sensor tend to consume more energy per pixel with performance requirement reduces. Also the energy required for each megapixel increases as resolution is reduced.

We can say from above that the measurements indicate that currently used image sensor's power utilization are not related to reduction of image quality if parameters like resolution and framerate are provided. Every case indicate, high energy consumption per pixel with reduction of the quality. Now let us see some mechanisms to see how we can reduce the power consumption.

Modifying Existing Mechanisms:

Mobile devices these days are equipped with CMOS image sensors. We will discuss it's hardware mechanism to reduce their energy utilization. Optimal setting of clock frequency and Texp of an image sensor in order to utilize the lowest energy per frame is discussed. Here we are assuming the resolution N and frame rate R. Two modes which are identified for this purpose are discussed:

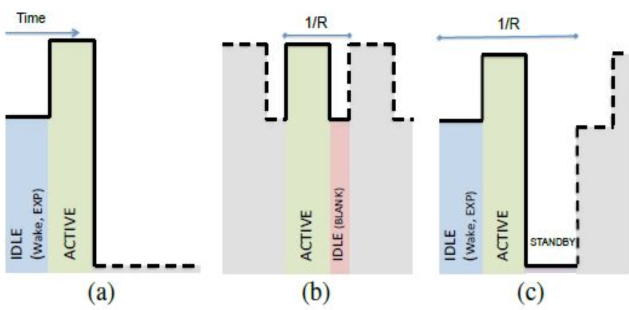


Figure 2: Power behaviour for single capture (a), standard sequential capture (b),and sequential capture with aggressive standby mode(c)

A. Clock Scaling:

New smart devices cannot modify the clock image sensor's frequency,which is denoted by f. The clock is provided externally in mobile systems, additional hardware, like programmable oscillator is required to change the clock frequency externally. The image sensor's energy utilization is remarkably affected by change in the clock frequency.

A.1 Single Frame Capture

This mode corresponds to image capturing action like clicking photo. The energy for a single frame capture,is given as follow:

$$P_{seq} = a_1 \cdot f + \frac{R \cdot N \cdot (c_2 - a_2)}{f} + B$$

P_{seq} reaches its minimum when $f_{best}^{seq} = (\frac{R \cdot N \cdot (c_2 - a_2)}{a_1})^{\frac{1}{2}}$.

For more details observe the above table 2.

	B1	**B2**	**B3**
a_1	4.0E-06	8.2E-07	3.35E-06
a_2	76.2	90.1	4.4
c_1	5.6E-06	1.0E-06	5.1E-06
c_2	159.0	93.0	13.1
f_{best}^{single} (indoor)	28.2	47.6	19.0
f_{best}^{single} (outdoor)	564.4	951.9	379.2
$f_{best}^{seq}(5\,FPS)$	10.2	4.2	3.6

Table 3: Parameters relating clock frequency f to power consumption.

Thus exposure time Texp and resolution N determines the image sensor's energy consumption in single frame capture mode

A.2 Sequential Capture

Sequential capture mode corresponds to video capturing mode. The power consumption as

$$P_{seq} = a_1 \cdot f + \frac{R \cdot N \cdot (c_2 - a_2)}{f} + B$$

can be given as following:

Ignoring standby mode, Hence for sequential capture the least energy consumption can be achieved by setting clock frequency considering resolution N and framerate R.

B. Aggressive Standby Mode:

Applying standby mode for the idle time in between 2 standby frames in sequential frame capturing. Which means that when the camera is capturing still image we can switch to standby mode. Please refer figure 5. The sensor consumes very less power when operating on standby mode. We will not consider the wakeup time (negligible) from standby mode.

$$T_{standby} = T_{frame} - T_{exp} - T_{active}.$$

For clarity and simplicity, we ignore the standby power, i.e., $P_{standby} \approx 0$, since it is very small compared to P_{idle} and P_{active}. We have

$$P_{seq}^{aggr} \approx \frac{P_{idle}T_{exp} + P_{active}T_{active}}{T_{frame}} \quad (16)$$

$$P_{seq}^{aggr} \approx a_1 \cdot R \cdot T_{exp} \cdot f + \frac{R \cdot c_2 \cdot N}{f} + D \quad (17)$$

We note P_{seq} achieves its minimum when $f = f_{best}^{single} = (\frac{c_2 \cdot N}{a_1 \cdot T_{exp}})^{\frac{1}{2}}$. As we see above, the best frequency depends on the exposure time, given the quality requirement.

$$P_{seq}^{aggr} \approx \frac{P_{standby}(T_{frame} - T_{active} - T_{exp}) + P_{idle}T_{exp} + P_{active}T_{active}}{T_{frame}}$$

Thus in aggressive standby mode, resolution and exposure time of the sensor's determines the optimal clock-frequency for sequential frame capture.

Thus we can conclude that,

Method	Energy Reduction
Optimal clock frequency- low-quality single-frame (Photo)	50%
Optimal clock frequency -sequential frame (Video)	30%
Low-power standby mode between two frame	40% (per pixel constant energy consumption at lower frame rates for sequential frame capture)

Table 4: Energy conservation in continuous vision using optimal frequency and expose time

ENERGY EFFICIENT HOTWORD DETECTION

With use of smartphones and other smart devices the developers are inspired to develop cutting edge application for ease of interaction with these smart devices. One of such application is “voice recognition”. Everyone is aware of ‘SIRI’ and ‘OK Google. These words are called as Hotwords. As well as the mobile system are become more and more voice interactive.

These kind of applications are energy draining and highly sensitive to implement. Another factor which matters is the accuracy of correct detection of algorithm. Conventionally microphone of device is used and the system looks like below figure:

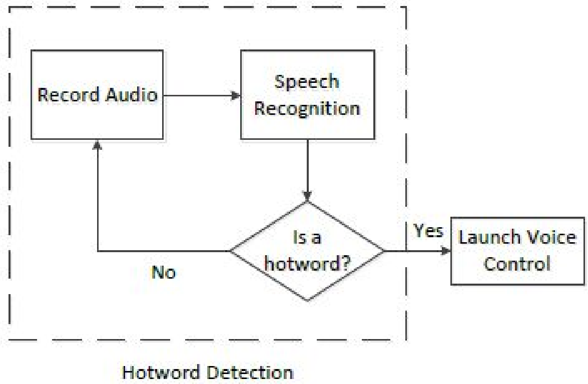


Figure 3: Flowchart of microphone based hotword detection

For accuracy and and optimal energy utilization accelerometer is used in modern mobile devices. The accelerometer is a used hotword detection, for solving problems like combating mobility of user, slow spoken words along with high energy conservation. But they are not very user friendly as sometimes the device is required to double tap the phone or wear a device. Hence Accelword system is used to overcome this difficulty.

The voice signals generate acceleration in accelerometer sensor. This signals are saved as accelerometer data and it accurately determines the variation is user’s voice every time. Hence a signature is extracted for each hotword. Machine Learning algorithm is used to train the prediction model. This helps in the classification on receiving the hotwords and the other words with lightweight voice signature matching.

For a hotword detection system all the features are very important accuracy, robustness like user mobility, Different voice frequency (female or male), Noisy surroundings. Along with all these energy efficiency, which we will discuss further.

The System Architecture of AccelWord

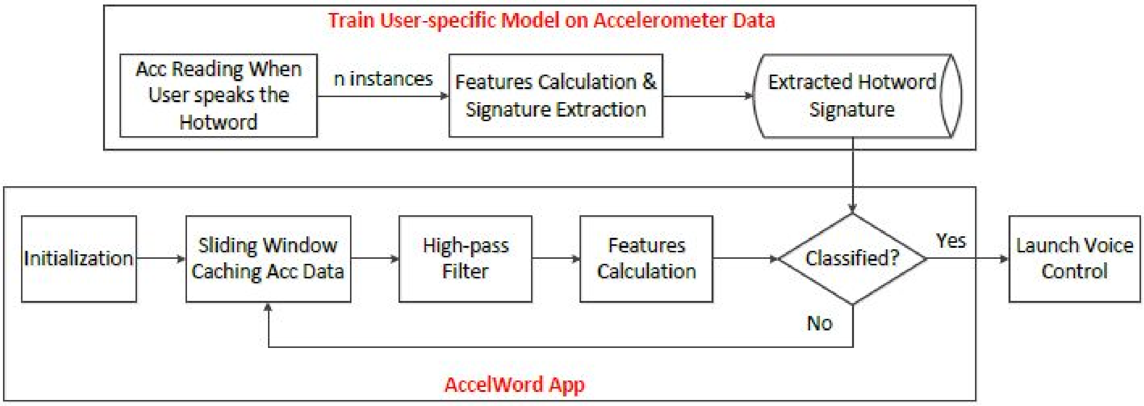


Figure 4: System Architecture of AccelWord

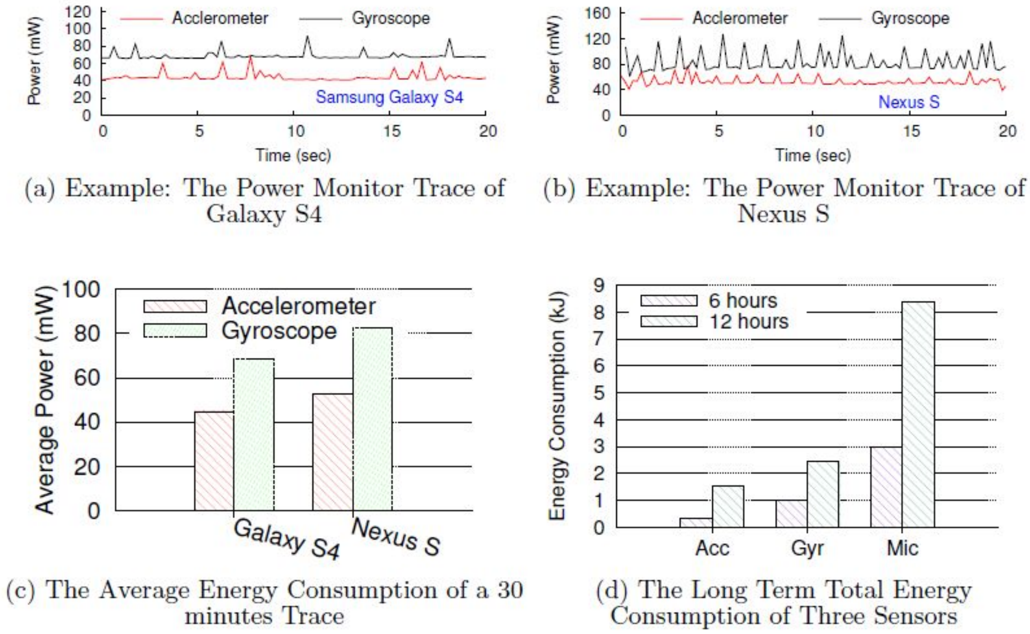
Above you can see the architecture of AccelWord. The figure is consist of each of the module Accelword is made of and the entire processing.

Using the AccelWord performs the following tasks:

1. Creation of signatures.
2. Signature extraction
3. Combating Mobility Interference
4. Training AccelWord Classifier

Energy Efficiency:

Here we can see the comparison between energy saved when Microphone,Accelerometer and Gyroscope is used.



(a) Example: The Power Monitor Trace of Galaxy S4

(b) Example: The Power Monitor Trace of Nexus S

(c) The Average Energy Consumption of a 30 minutes Trace

(d) The Long Term Total Energy Consumption of Three Sensors

Figure 5: Energy comparison between Microphone,Accelerometer and Gyroscope

Statistics for Energy conserved with Accelerometer:

Method	Galaxy S4	Nexus S
Google Now	46.19%	53.85%
Samsung S Voice	57.14%	N/A

Table 5: Energy conservation for hotword detection using AccelWord

LOCATION SENSING

In this modern age of smartphones, applications providing location sensing are becoming increasingly popular. For location sensing, GPS receivers are largely preferred over its alternatives due to its high accuracy. And its active usage causes large amount of battery surge due to their power consuming location-sensing methods.. In this part of the paper, we present energy efficient location sensing by analyzing various prototypes, applications, techniques and frameworks for adaptive location sensing. Aloc is an adaptive location sensing service which manages the location sensor availability, accuracy and energy thus providing significant energy saving along with accuracy. While another technique provides reduced energy consumption by periodically duty-cycling GPS. Whereas, CellID sequence matching leverages continuous mobility and position history of users rather than cell-tower based approach while keeping lower energy overhead. We have also discussed a framework which considers substitution, suppression, piggy-backing and adaptation of application's location sensing requests which saves energy.

Observations have shown that the requirement of location accuracy varies with location. So, Aloc is based on the approach that the location precision is not always required and there are many methods to sense locality other than power hungry GPS such as Wifi triangulation, Cell-tower triangulation, Bluetooth vicinity etc. According to the user's mobility, the availability and accuracy of this methods changes and accordingly the method can be selected which meets the location needs and lower energy costs.

Aloc

Aloc considers multiple factors at higher level. Dynamic accuracy requirement is the block which determines the location precision which is the requirement of the applications. Sensor energy model characterizes the uses of energy by each location sensors in obtaining locations. Dynamic Sensor accuracy model characterizes the quality of location information provided by each sensor. Sensor selection algorithm decides which sensor is to be used at each step during the process.

In the standard Bayesian framework used in the sensor selection algorithm, Aloc's accuracy model for a modality i is represented by using probability distribution $p(z_i(t)|x(t))$. The curve of distribution is assumed to be two-dimensional Gaussain distribution centered at x(t).

The standard deviation *σx(t)* changes with the error for the sensor at x(t). GPS estimates its error through horizontal dilatation of precision. Energy models for all the modalities are measured considering locations and exterior components that may affect the energy usage. Wifi triangulation technique is followed up by powering up the wifi radio, scanning the access point identities and powering down the wifi radio. The graph for energy usage is initial energy spurt for initialization and straight line for scanning. The data for matching SSIDs and triangulation is assumed to be available on phone and the size of such data is 20 MB. The energy usage by the 3G radio for communicating with server is much higher. Localization using Bluetooth is followed up by scanning the Bluetooth identities in proximity. The energy usage is higher compared to wifi because it takes much longer time for scanning. Cell-phone keeps the record of cell-towers which is obtained by its radio receiver. On the basis of this, a phone can determine its location. The energy usage for modality is low as it just has to read the data available on phone. The table below shows the energy usage of different location sensing modalities.

Location sensing modalities	**Its energy usage**
Wifi triangulation	115mJ(turning on), 65mJ(turning off)
Bluetooth vicinity	160mJ(power up), 35mJ(power down)
GPS	1425mJ
Cell-tower association	20mJ

Table 6: Energy usage in location sensing modalities.

Location Sensing framework: Substitution, Suppression, Piggybacking, Adaption

Another location sensing framework ameliorates the coherence of the energy for location based applications. The framework includes four design principles: Substitution, Suppression, Piggybacking and Adaption. Substitution uses alternate location sensing technique such as network based location sensing that uses much less power than GPS. Suppression is a technique which uses less power consuming sensors such as accelerometer to lower down non-essential GPS sensing when the user is not in mobility. Piggybacking integrates the location sensing requests from multiple applications. Adaption adjusts common measurements such as distance and time.

Whenever GPS is taken into account, applications get the accurate location. But in some remote areas, if GPS is not working properly than continuously looking for GPS is not good for battery-life in terms of energy. **Substitution sensing** is a technique which chooses the most energy-efficient location sensing mechanisms. Selection of the location sensors is done dynamically and to achieve this substitution sensing technique depends on some characteristics such as availability and precisions of location sensors. And due to this reason, substitution sensing includes a technique known as profiler. Profiler analyzes and stores data such as frequency of the visited locations, current locations, availability and accuracy of sensors. Based on this data, substitution sensing determines the most energy efficient location sensor.

Smartphones are used in many different scenarios. And many times, it happens that location sensing is not required when the phone is static. In such cases, energy can be conserved by suppressing or stopping location sensing. This technique is called **Suppression Sensing**. It is based on the principle which detects the transitivity of the phone using less power hungry sensors and lower down unnecessary calls for location sensing. There are many different research works which determines the mobility of the phone such as SoundSense, accelerometer, orientation sensor etc.

Piggybacking Sensing is a technique which uses the prevailing sensing informations by piggybacking new sensing request on prevailing ones, thereby reducing the number of location sensing calls. Piggybacking sensing work efficiently when multiple location-based applications are running concurrently. Location sensing requests and registrations made by different applications are in many ways. Applications may use one-time registration or many-time registrations. Piggybacking sensing is mostly useful for many-time registrations by piggybacking redundant request on existing ones.

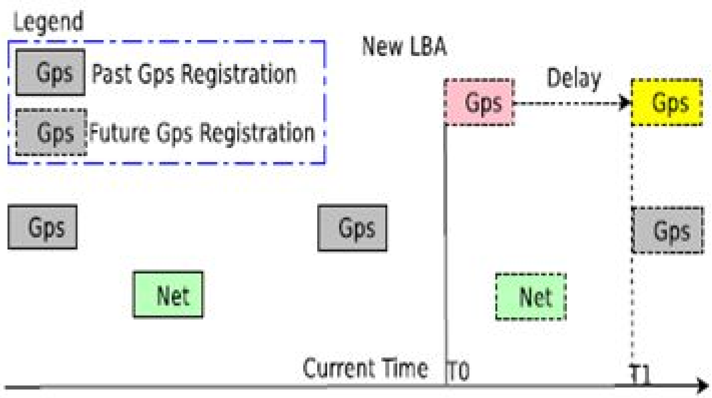


Figure 6: Sensing Piggybacking

Adaption Sensing is a technique which adapts the intervals of the location sensing based on the user preference for battery life or accuracy. Adaption sensing is implemented in three different ways: a) adjusting the aggressiveness of design criteria b) changing sensing intervals c) changing distance sensing intervals. The four techniques discussed above can work in integrated environment. Figure 2 shows the integration of all the techniques.

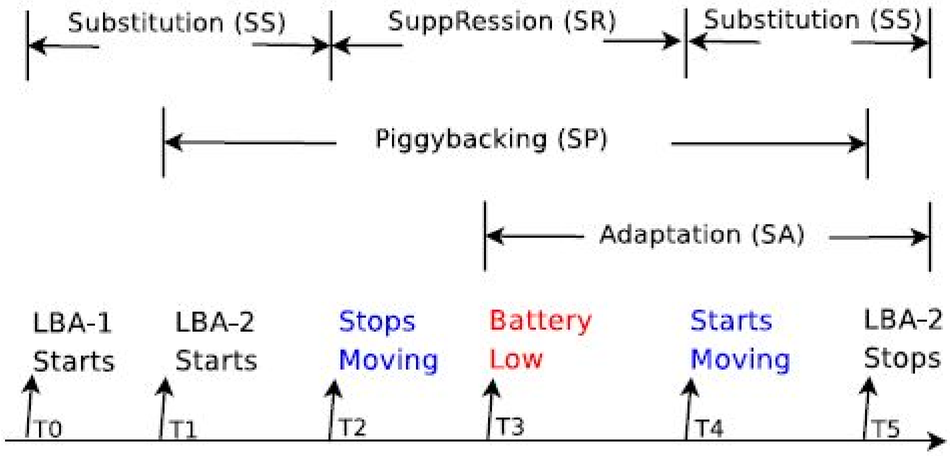


Figure 7: Integrated operations

Performance evaluation of all the techniques can be carried out by individually and then in the integrated environment. Use of sensing substitution technique reduces the number of calls for location sensing by 50%. Suppression sensing reduces the energy usage by calls upto 400. Piggybacking sensing reduces the location invocation upto 50%.

NETWORK BASED TRAFFIC MANAGEMENT: Catnap

Other than the location service, network activities also consumes significant amount of power. Due to increase in the usage of smartphone, network activities such as web browsing, emails, maps, sharings etc have increased the network traffic to a greater extent. Growth in the network traffic demands large consumption of energy. Therefore, energy management is required for better productivity. Catnap is a technique that allows the devices to sleep in between data transfers for energy conservation.

Catnap is a technique which saves energy by meaningful sleeping in the gap between the packets. The gaps are created in the path because the high bandwidth link is given an overhead by the slower links. Catnap majorly works on three concepts: Firstly, it separates wired segments and the wireless segments and allows one of them to sleep when the other is transferring data. A function that seperates wired segments and wireless segments is called middlebox. When the device is sleeping, middlebox collects the bunch of packets and provides all the packets to the device when it wakes up. Secondly, catnap uses common units of transfer so that it remains application independent. Yet, they can know the requirements of the applications. Thirdly, middlebox uses bandwidth estimation technique. This technique determines the bandwidth of wired and wireless path.

Application Type	Examples	Catnap Strategy (Target Device)	Expected Benefits	Remarks
Interactive	VoIP	None	None	Device and NIC remain up to maintain user experience
Short Web Transfers (<100kB)	facebook google	Batch Mode (Small Devices: Smart Phones, Tablets, etc.)	30% NIC sleep time	- Embedded objects rendered together - Batching may require some app. specific support at the proxy (e.g., java scripts)
Medium Sized Transfers (128kB to 5MB)	you-tube flickr images mp3 songs	Normal Mode (Small Devices)	up to 70% NIC sleep time	No impact on user experience
Large Transfers (>5MB)	maps & movies software updates	1. Normal Mode (Small Devices) 2. S3 Mode (All Devices)	1. >70% NIC sleep time 2. 40% device sleep time for a 10MB transfer	1. No impact on user experience 2. User permission to enter S3 mode is desirable

Table 7: Energy usage in Catnap technique

Table 1 shows the energy usage and benefits for different application by catnap. As it can be seen that, for a smaller data transfer, Catnap can put NIC to sleep almost 30% of the time and for medium sized data transfer, sleep time is up to 70% and for larger data transfer, Catnap can put NIC to sleep for a sleep time of greater than 70% of the time.

CONCLUSION

In conclusion, energy conservation is the major requirement in today's world. In our study of different researches presented in SIGOPS, we analysed the implementation and evaluation of network based traffic management technique,Catnap, which converts 70% of the total transfer time into sleeps thereby contributing to energy saving. And the methodologies like Aloc and location sensing frameworks provide significant energy saving that goes beyond conventional systems. As seen in above sections the alternatives like adjusting clock frequency and configurations of exposure time reduced the energy consumption by camera in different modes like image capturing and video capturing. Also accelerometer based voice recognition replacing the conventional microphone has overcome problems of user friendliness, slow spoken recognition along with conservation of energy. Such techniques can inspire developers in mobile application domain to come up with more and more innovative ideas without bothering about the energy utilization. The applications and implementation of this techniques provides further research challenges and opens the door for relevant future work.

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Note: All the following references are cited in MobiSys events, conducted by SIGOPS

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