REPURPEL

REPURPOSING END OF LIFE ELECTRONICS

Remanufacturing Feasibility Project

by

aXr Ltd

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Introduction

In recent years there has been growing concern about the negative impacts that industry and its products are having on both society and the environment, and the concept of sustainability has received increasing attention. One area in which there has been much concern about the lack of sustainable behaviour is in the manufacture, use and disposal of electrical and electronic products. The electronics industry provides devices that are essential to the modern way of life and yet it has also not operated very sustainably. In fact, electronic products are typically characterised by features, such as improved performance and reduced cost in each new generation of product, that actually encourage unsustainable behaviour. Many electronics products such as mobile phones are rapidly discarded in favour of the latest model. This has lead to increasing quantities of end of life electronics being consigned to waste streams.

Waste Electrical and Electronic Equipment (WEEE)

In the past, any reference to the treatment of end of life electronics would only have been about the recycling of materials, which basically meant the recovery of metals. However, in terms of both more sustainable approaches and recovered value, there
is a clearly defined hierarchy that can be applied. This may vary somewhat, depending on the specific product type, but in general terms the preferred order of approach at end of life is as follows:

- Refurbish and reuse
- Repurpose
- Recover and reuse functional modules
- Recover and reuse components
- Recover materials
- Produce raw material feedstocks
- Recover Energy

Therefore, within the overall electronics reuse, recovery and recycling hierarchy, the key opportunities are for the reuse of individual functioning units, modules and components. There are now many organisations that are actually refurbishing electronic products for reuse and this has been particularly evident with mobile telephones and personal computers. These organisations often operate as social enterprises in order to offer low-cost access to products for those that would not otherwise be able to afford new products. This has enabled wider communications, computer and internet access to people both in the UK and, for example, to school children in the poorer parts of Africa.

However, where it is not possible to refurbish and reuse electronic products, the next best approach, and the subject of this work, involves repurposing certain types of electronics. Although this approach has not yet been exploited to any degree, the increasing sophistication of some electronic devices, such as mobile phones and portable gaming equipment, means that they are potentially suitable for use in other applications. In the case of mobile phones, the latest products contain very advanced processing and communications capabilities that could be harnessed for new applications, yet they are often discarded after very short use lifetimes of typically 12 months or less. Considering that there were over 2 billion mobile phone users globally in 2005, this represents a waste of large quantities of valuable
components, raw materials, energy and electronics functionality. (It has been estimated that if all of the redundant phones in the UK were collected they would weigh around 7,500 tonnes).

Lifecycle assessment (LCA) studies have found that one of the most significant impacts of a mobile phone on the environment is the energy used to manufacture the phone’s components. For example, manufacturing just one 32 MB RAM module requires 32 kg of water, 1.6 kg of fossil fuels, 700 g of gases and up to 72 g of different chemicals. The premature disposal of these high performance devices is not sustainable and can also lead to potential environmental issues associated with traditional disposal routes.

In this project, work has been carried out to examine the feasibility of re-purposing mobile phones into generic smart processing units for reuse by manufacturers of new electronic equipment. By repurposing redundant units and converting them into general purpose modules, they have the potential for reuse as core components in a wide range of applications such as those requiring smart monitoring, sensing and telemetry capabilities. Applications could range from relatively simple burglar alarms and monitoring, to advanced mobile medical diagnostics for use in remote locations.
The REPURPEL Concept of Mobile Phone Repurposing showing the transition from a phone to a module used in a new product

While this approach may only be applicable to a number of sophisticated, high volume electronic products, it does offer interesting possibilities that avoid the conventional disposal and recycling routes and it is clearly worthy of further investigation.

There are a number of high volume sophisticated products that could lend themselves to repurposing and reuse in new applications, the best example being mobile telephones. The REPURPEL project has carried out a study to determine the feasibility of repurposing and reusing specific types of end of life electronic products and to identify the barriers and opportunities. The work was carried out in the context of also identifying the potential financial and environmental benefits, such as resource and energy use optimization, landfill diversion and green house gas reduction. The project has been undertaken by aXr Ltd and Sheffield Hallam University with further additional inputs, support and in-kind contributions from a number of interested organisations.
Project Objectives

The key objectives of this feasibility study were to determine which specific types of electronic products would be most suitable for repurposing and to identify potential applications. Whilst it was initially known that mobile phones and possibly portable gaming machines were likely to be most suitable, it was necessary to identify specific types of equipment within each of these categories, since they have widely ranging capabilities, software operating systems and interfacing.

Another objective was to make an assessment of the technical, financial and other challenges that would need to be addressed if specific potential repurposing scenarios were likely to be commercially viable. As part of this objective, the project also sought to identify the environmental benefits associated with the repurposing of electronics when compared to using new products and disposing of old ones.

Additionally, and specifically, the project had a focus on determining the feasibility of re-purposing mobile phones into generic smart processing units for reuse by electronic equipment manufacturers. A key activity here was to determine if this could be achieved by utilizing the advanced computing and connectivity capabilities of mobile phones and to identify which phones, if any, would be most amenable to repurposing. Assessments were made of the ease of repurposing specific units.

Finally, and perhaps in some respects most importantly for future work, a substantial part of the project was dedicated to the development of repurposed mobile phone demonstrator units.
The Feasibility Study

Overview and methodology

This short study, conducted over a six month time frame, had a number of key activities. These, and the approaches taken are described individually in this section but the project can be considered to have had two main elements; namely a focus on activities around the assessment of the potential challenges, benefits and opportunities of repurposing and the development of simple demonstrator units that could prove proof of concept. Both parts of the project were critically important. Only a detailed assessment of the benefits of repurposing would enable a properly informed decision to be made as to whether or not repurposing would ever be considered a viable opportunity. A detailed technical assessment and development of a simple demonstrator would also be necessary to confirm that the approach was indeed technically viable and to enable a better level of knowledge to be gained about the specific technical challenges associated with repurposing. These activities were run in parallel during the project and bringing the results of both approaches together at the end of the study has enabled a much better understanding of the overall possibilities for repurposing. The individual aspects of repurposing that have been studied during the project are now detailed in the remainder of this section.

Technical issues and challenges

An important issue when repurposing sophisticated electronics such as a mobile phone is that of data security. There have been concerns raised about residual data that is contained in the memories of mobile phones that have become available for repurposing. In particular, the issue of information security has grown significantly with the increasing use of multi-function smart phones that store e-mail messages, contact information and calendar entries, with the average smart phone being capable of storing thousands of documents containing confidential information. Where a mobile phone has been consigned for conventional recycling there may not be too much of a problem since the phone will be destroyed. However, where a unit is likely to be repurposed, there will be much more of a possibility for residual confidential information to fall into the wrong hands. Therefore, before mobile phones are likely to be accepted as the basis for new electronic modules, many providers of redundant phones will require guarantees that any residual data will be
removed from the phones prior to repurposing. While this is clearly an important consideration, there are ways in which security can be achieved and standards applied, the requirement of which if met, can give a good level of confidence that there will be no residual data retained in the repurposed unit. Such approaches have already been adopted widely for use with computer hard discs and standards such as the US Department of Defense’s US DOD5220.22 are an often used to ensure that data is no longer retrievable.

Other challenges around the use of end of life repurposed electronics include the concerns new users may have about employing used electronics in new products. While some of these concerns may be more perceived than real, attention will rightly need to be applied to ensuring that any repurposed electronics can meet the performance requirements of a specific new application and that it will be able to meet the same lifetime and reliability requirements as newly built equipment. This will be particularly important in safety critical applications such as medical monitoring, where an unexpected failure could have serious consequences. Whilst mobile phones are usually discarded very early in the functional lifetimes, they can still have experienced widely varying use patterns and operational environments.

A key part of any repurposing operation will be a testing and refurbishment stage that includes critical segregation of the best quality products, followed by a strict quality controlled testing and evaluation procedure to ensure that the products selected are fit for a specific purpose. Those that are selected will then need to be subjected to a data wiping/security risk minimisation operation that is able to guarantee that there is no residual data remaining on the repurposed unit. Clearly, there will be a cost implication associated with these operations and this will have to be factored into the overall costings for producing repurposed units.

The ability to repurpose end of life mobile phones and other electronics could also be aided by due consideration at the design stage. For example, the recycling of plastics from dismantled phones can be limited because of the brominated flame retardants they contain. Disassembly for repurposing could be more easily facilitated by attention at the design stage e.g. by removing toxic materials, using
fewer types of plastic and, specifically in regard to repurposing, using fasteners etc that allow for easy disassembly. Using these design strategies would lead to easier dismantling, as well as enabling unwanted materials to be recycled and thus reduce the costs associated with the overall repurposing operation.

The main obstacle to implementing such design approaches is that there has traditionally been no link between the design of a product and its end-of-life management. When producers bear none of the costs for managing their products after consumers discard them, they have little incentive to create designs that facilitate reuse and recycling. However, with producer responsibility legislation, such as the WEEE Directive, now in force across Europe, manufacturers can no longer ignore end-of-life management costs. They thus have a strong incentive to reduce these costs by designing products that generate less waste and whose parts and materials are cheaper and easier to reuse and recycle. Establishing links between product designers and end-of-life management would therefore be a good way of ensuring that products are designed that can be viably repurposed.

**Suitability of products for repurposing**

There are a number of important issues that need to be taken into account when considering a particular electronics product for a new repurposing application. Clearly, an initial and fairly obvious requirement is that the product to be repurposed actually has the required functionality to meet the demands of the new application. This is likely to require the ability to convert the phone into a central data collection, processing and transmission unit that can carry out a number of functions, including for example;

- handling incoming data from a variety of sources, e.g. sensors and transducers which can be hard-wired to the device or which connect via as standard existing interface such as Bluetooth or infrared.

- processing the incoming data and taking suitable action depending on the data
transmitting and receiving data, to and from another location, and enabling decisions made at the remote unit to be communicated via the central unit to the sensors and transducers.

The ease with which this can be achieved depends to a large extent on the type of unit i.e. mobile phone being repurposed, since factors such as the ability to hard wire connections as well as to modify the operating systems software are known to vary significantly from product to product. The operating systems (OS) on most mobile phones appear to be based on Symbian or Microsoft’s Windows CE and Mobile products. Symbian is the leading OS in the 'smart mobile device' market. Statistics published in 2007 gave Symbian OS 67% of the 'smart mobile device' market, with Microsoft having 13% RIM having 10% \[1\]. Symbian is currently owned by Nokia (47.9%), Ericsson (15.6%), Sony Ericsson (13.1%), Panasonic (10.5%), Siemens AG (8.4%) and Samsung (4.5%).

There are known to be differences in the ease of reprogramming mobile phones depending on which operating system is in use and this may well influence the choice of phone that is most suitable for a particular application. Also although Symbian is the dominant operating system used in the majority of phones, there are in fact many other operating systems in use in other phones. In terms of suitability for repurposing it may be that only phones using the dominant operating systems will be suitable for repurposing i.e. where there is strong OS development user community and thus plenty of accessible information. For example, although Symbian is the dominant OS, one of the biggest differences when between Symbian and Windows Mobile software is the speed of the latter. Developers working with Windows Mobile can get results more quickly because the development tools and operating system are streamlined and harmonized and because there is a huge amount of documentation and online support available for Windows Mobile. These differences may well be important factors in helping to select a specific phone for repurposing into a particular application.
Environmental benefits assessment

As a result of the relentless progress in the electronics industry, with each successive generation of products typically having improved performance at a lower cost, many electronic products have effectively become disposable items that are discarded long before their real service lives have expired. This is particularly true with mobile phones where product lifecycles are often less than a year and, on average, mobile phone users replace their handsets every 18 months (or 11 months for under 25’s). The desire to obtain a new mobile phone is also driven by the way mobile phone service providers structure their contracts to give users a new mobile phone when renewing an annual or eighteen month contract. This is clearly not a sustainable use of valuable resources and there is much published data indicating the negative impacts of replacing mobile phones at such short intervals. When one considers that around 100 million mobiles are thrown away in Europe each year and that 50 million mobile phones are bought in the UK each year, the scale of the problem is put into context. There are believed to be more than 11,000 tonnes of surplus phones in the UK and it has been estimated that making one 90 g mobile phone generates 36 kg of carbon dioxide. Thus the UK’s annual purchase of new mobiles contributes 1.8 million tonnes of carbon dioxide emissions to the atmosphere.

In addition to the energy consumption associated with their manufacture mobile phones also contain a wide range of materials including some which are especially valuable, some which are in relatively finite supply and some which present environmental and health hazards. Mobile phones typically have a scrap value of around £2000 per tonne (varying with metal prices). By disposing of mobile phones, particularly where they are consigned to landfill, valuable and finite materials are being lost, while at the same time noxious materials are entering the environment. For example, heavy metals such as mercury, lead and cadmium are often present within mobile phones, especially older models, and various brominated flame retardants can be found in the printed circuit board laminates and the plastic casings. A few years ago the rapid growth in production of mobile phones meant there was a huge increase in the use of tantalum electrolytic capacitors which increased demand for the raw materials used to make them. This increased demand forced the price of
Coltan (colombo tantalite) to increase from around £30/kg in 1990 to more than £550/kg. The resulting increase in mining activity in the Democratic Republic of Congo was directly responsible for the demise of many mountain gorillas that were killed and eaten by the miners. This is a sad but interesting example of how man’s desire for the latest electronic products has a much wider detrimental impact on the natural environment.

Ideally, users of mobile phones should be encouraged to keep them for longer periods so, for example, they could be used for say two years rather than just one. Considering that mobile phones can have realistic service lives of as long as seven years, this would be unlikely to cause any major issues. However, this does seem to be an unlikely scenario and thus, if one accepts that mobile phone service lives are likely to continue to be relatively short for the foreseeable future, the next best options are other to pass the units on to other users or to use them in a repurposing application. It also has to be acknowledged that the latest phones produced by many of the more environmentally aware manufacturers are much more efficient in terms of materials and energy use and have less impact than their predecessors. Many current mobile phones now weigh less than 100 g (compared to the 1 kg of early handsets), they use less energy in operation and have talk times of more than eight hours with standby times of several weeks. Some companies have gone even further and the Japanese company NEC has produced a mobile phone that has its plastic casing made from a renewable (i.e. non fossil fuel) source. The phone uses a plant-derived bio-plastic which is reinforced with a natural fibre to give it the required properties. The phone’s manufacturing process is also claimed to emit 50% less carbon dioxide than conventional approaches because of a shift away from fossil fuel-based power generation

**Life Cycle Assessment (LCA) considerations (overview)**

Although there are large and increasing quantities of mobile phones being discarded each year that are thus potentially available for further treatment at end of life, it is not necessarily clear which treatment routes are to be preferred from an overall environmental benefits perspective. There are many factors that have to be considered when attempting to define the preferred treatment methodologies for end of life mobile phones and to determine if there are specific benefits associated with
repurposing. In order to gain a more holistic understanding, it will be necessary to undertake some form of life-cycle assessment, which considers all aspects of a phone’s life from raw materials sourcing to end of life options, including all phases in between. This type of approach is, however, quite often extremely difficult since much of the required data may be elusive or possibly not even available. Other challenges in undertaking such LCA studies include where exactly to set the boundaries and deciding how complex the LCA needs to be. Some relevant work has been carried out on mobile phones by various companies such as Nokia and the available published information has been reviewed. This information is summarised in the more detailed section on mobile phone LCA that is included as Appendix G at the end of this report. For the sake of brevity, only the most important LCA related considerations specific to repurposing are reviewed in this section, and for more detailed information, reference should be made to Appendix G.

In terms of the life cycle assessment approaches related to the adoption of repurposing as a viable end of life scenario, the considerations would be a comparative assessment against other possible treatment options. Essentially, the drivers for adopting repurposing could be split into two groups, namely those related to the financial viability and those specifically associated with the environmental aspects. If repurposing is to become a serious alternative to the alternative of building new, application specific electronics, there must be positive financial reasons, or manufacturers will continue to manufacture new products. Ideally, repurposing should offer both financial and environmental benefits, but this is by no means a certainty and some detailed analysis will need to be undertaken on the both aspects. What is clear, however, is that without a real financial benefit, repurposing is likely to have limited applicability, irrespective of the outcomes of any life cycle assessment.

**Logistics of Collection**

As with all recycling operations, one of the biggest challenges for repurposing is organising the collection and movement of the items to be treated from the end user to the treatment/ repurposing centre. For mobile phones which are destined for repurposing, there will be a need to move the phones from end users to one or more
repurposing centres. Typically, in the case of low value materials that are found in a wide range of disparate locations, the cost of transporting to central treatment facilities is often prohibitively expensive in terms of the subsequent value of the treated goods and this can make recycling non-viable. However, in the case of mobile phones, the situation is somewhat different because they are, individually, relatively light in weight (≤100 g) and have a high value. Additionally, the repurposed units could even have a subsequent value that may be greater than that of the original phone, meaning that the transport costs would only represent a very small proportion of the overall ultimate value of the products. Currently, on an individual basis, a phone weighing less than 100 g can be posted within the UK for less than £1.00. So, for those people who would be willing to donate their old phones, a scheme could be established to provide a prepaid ‘envelope’ or free post address that could be used to ship the phone directly to a repurposing centre. This is in complete contrast to the case for applying to large white goods such as washing machines and fridges. The unique nature of mobile phones makes the logistics of recycling relatively straightforward and gives a process that is effectively self-sustaining (ie the yielded value exceeds the processing costs). Key factors are;

- the small size and weight of phones which minimize transport costs
- a market for repurposed phones
- the precious metal value of non-repurposable mobile phones
- the minimal hazardous material content

While there are undoubtedly large quantities of suitable mobile phones available for repurposing, there are also a number of companies competing to acquire them. These organisations typically purchase a wide range of used mobile phones and some of the more recent smart mobile phones have an appreciable second hand value. For example, the global mobile phone recycling company ‘MobilephoneXchange’ is currently (14/05/08) offering the following prices for second-hand phones;
<table>
<thead>
<tr>
<th>Phone</th>
<th>Price/£</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nokia N95</td>
<td>102</td>
</tr>
<tr>
<td>LG KE850 Prada</td>
<td>47</td>
</tr>
<tr>
<td>Sony Ericsson K810i</td>
<td>39</td>
</tr>
<tr>
<td>Samsung U600</td>
<td>38</td>
</tr>
<tr>
<td>Nokia 6300</td>
<td>36</td>
</tr>
</tbody>
</table>

There are also organisations that, while operating their own mobile phone recycling schemes, also help other organisations to establish schemes. CMR, for example, manages mobile handset take-back schemes for a number of retailers throughout Europe and offers a full audit trail. In terms of competing with established organisations for mobile phones, it is likely that some form of differentiation may be required in order to secure supplies. For example, one organisation in Australia offered to plant a tree for each phone supplied for recycling and the campaign was so successful that 20,000 phones were collected in two weeks. This enabled 20,000 trees to be planted which was estimated to be equivalent to offsetting 3,000 tonnes of carbon emissions or taking 1,000 cars off the road.

In summary, it appears that the logistics of collecting suitable mobile phones for repurposing should, compared to other larger and less valuable products, be relatively straightforward. In terms of the likely numbers of phones required for repurposing, it is unlikely that there will be any lack of availability, although ways will have to be found to ensure supplies can be obtained in an area where there is a substantial amount of competition.
Application Concepts

Potential applications

This section gives an overview of some of the potential applications of repurposed electronics such as mobile phones and then details one specific example of a potential repurposing application for a redundant smart phone which has been developed through several stages of increasing complexity. Because of the increasing sophistication of mobile phones and the increasing incorporation of features such as short-range wireless i.e. Bluetooth and GPS, along with higher resolution cameras, there is a growing number of potential opportunities that are specifically suitable for this type of device. There has, for example, recently been recognition from OFCOM, of the wide potential for exploiting Wi-Fi devices and in a recently published report [1] they concluded that wireless communication was ‘integral to all our lives’. Although the potential for this type of wireless approach using repurposed end of life mobile phones is very wide, two of the key potential areas for exploitation are likely to be in the healthcare and transport sectors. For example, remote medical diagnostics could be achieved using a range of sensors that communicate with repurposed electronic modules to monitor the condition of a patient and to alert either the patient or a carer/doctor etc. This could be as simple as reminding a patient to take his or her medicine or something much more sophisticated. A range of on body, or even in body sensors, could be used to continuously monitor the condition of person and to send data to a doctor or carer if their condition required attention. This could again be as simple as having a series of motion sensors located around a house to monitor a person’s movement patterns or something more sophisticated, for example, including wearable or implanted sensors.

In addition to healthcare opportunities, repurposed electronic modules working in tandem with an appropriate suite of sensors could be used to enhance travel and transport by road and rail. Cars could each be equipped with modules enabling them to communicate with each other to provide local information, such as braking activity in the car ahead, to more widespread monitoring of traffic flows and road conditions. The whole area of intelligent transport is one that is of growing interest to car manufacturers and one that will require a large amount of electronics capability.
The European Commission is currently debating whether to allow the so called ‘e-call’ or automatic emergency call out, which would automatically call the emergency services in the event of an accident. These types of applications would appear to present an ideal opportunity for repurposed electronic devices.

Potential applications

In this case, the smart phone under consideration for repurposing is the Sony Ericsson P800, a predecessor of the P900. This was chosen because it is a popular example of a smart phone that has found widespread use and which is also available at end of life in good quantities. As newer models begin to find their way to end of useful life and appear for recycling, they could also be used as an alternative. In this example, a step by step approach has been taken to consider a range of potential application designs ranging from a relatively simple application to one that is significantly more complex. These examples were considered prior to the development of the actual physical demonstrator models that were also produced as part of the project. They are thus complimentary to these demonstrator designs that are discussed elsewhere within this report.

Alarm Surveillance Unit

One potential repurposing application for a redundant smart phone is to use it as a key component in an Alarm Surveillance Unit. In the initial stages of the project, it was anticipated that the project would use the widely available Sony Ericsson P800 smart phone, because it was a good example of widely available smart phone that was nearing the end of its service life. The basic general concept for a relatively simple design is as shown below:
This general basic design concept requires the P800 to be connected to the microprocessor which is in turn connected to the Alarm System. In this simple example, the P800 has the ability to retrieve data from the Microprocessor via a wireless connection such as Bluetooth, or Infrared. The P800 could also be able to receive emergency calls when the alarm system is activated and is modified to incorporate additional functionality to enable it to retrieve data from the microprocessor. This could include images captured from the CCTV (Closed Circuit Television) and data identifying the exact location where the alarm was activated.

This simple type of Alarm System would be of use in a Burglar Alarm System which is installed in a house or a building. The alarm would be activated by a variety of sensors typically utilised in this type of application. In a slightly more sophisticated version of the alarm system, a control feature may be added whereby the P800 could be used to control the position and movement of cameras to enable scanning around the building. The system will activate the alarm as well as making a direct call to the P800 indicating an intruder is in the building. The user will then be able to retrieve images by controlling the CCTV around the building. The P800 has also the ability to activate or deactivate the alarm system.

In order to develop these design concepts a step by step approach to the design stages is discussed in the following:
1st Stage of Design:

The first stage of design is as shown in the figure below:

![Diagram of 1st Stage of Design]

The first stage of design is to develop and incorporate a modular circuit board assembly which can be connected to a microprocessor. The microprocessor is a programmable prototype that synchronizes with the circuit board assembly created for the Alarm System. Programming is achieved by via connecting the microprocessor to a computer thus enabling a programming sequence to be downloaded to the microprocessor via the computer. The circuit board assembly will contain sensors such as an infrared system, an alarm bell and an indicator which will provide information of alarm activation to the P800. For this stage, the P800 will be connected to the circuit board assembly via a cable connection such as an RS232 serial or USB (Universal Serial Bus) cable.

When the infrared detector is triggered, an electronic switch which will activate the bell and the signal is transmitted to the bell, an alternative signal from the circuit board assembly also be transmits data to the P800 which will advise the user of the alarm’s activation.

2nd Stage of Design:

The second stage of design represents a slight more sophisticated approach then detailed in the first stage of design. The figure below illustrates the second stage of the design idea:
In this design, there will be an upgrade to the connectivity of the P800, and a wireless connection, e.g. Bluetooth will retrieve data from the Alarm System. A transmitter will be connected to the main circuit board of the alarm system. This transmitter is used to transfer data to the P800 and retrieve data from the alarm system. The transmitter can be similar to the systems used on wireless house phones where the system only recognizes the frequency used by the wireless phone. When receiving incoming data, the transmitter will send a signal to the wireless phone. This design offers additional convenience because the user will be able to receive the signal at a distance from the main unit.

It may also be possible to incorporate a direct call system where, for example, the transmitter is replaced with another telephone circuit board where a SIM (Subscriber Identity Module) Card is fitted into the system. When a signal is received, the phone circuit board will make a direct call to the P800 indicating the type of event that has taken place. In this type of application it can be seen that there is the potential to use two repurposed end of life mobile phones.

3rd Stage of Design:

For the third stage of the design, additional features will be added to the main circuit board of the alarm system. In this stage, a CCTV (Closed Circuit Television) and a memory device will be included. The figure below illustrates this design concept:
From the diagram, a memory device will be inserted into the main circuit board of the alarm system so that it is possible to store images captured from the CCTV. The images can be retrieved by the P800 through the transmitter where the image data can be obtained from the memory at anytime required by the user and the user.

**4th Stage of Design:**

The fourth stage of the design incorporates an additional capability to control the CCTV. The figure below shows the implementation of this design:
In this design, an external control circuit board will be attached to the main circuit board of the alarm system enabling the remote control of CCTV cameras.

5th Stage of Design:

The fifth stage of the design incorporates further levels of sophistication and more features have been included to the whole system. The figure below shows the design:

In this stage of design, another wireless control system is included to the main circuit board of the Alarm System. This wireless control is connected to the Control Circuit Board. The wireless control will then be the controller for the mobile CCTV system. This wireless connection can be achieved by using Bluetooth or similar wireless technology, as this technology has a wide single transmission range even enabling control from behind a thick wall. The mobile CCTV consists of an internal main control circuit board which is connected to a wireless transmitter or receiver and an internal memory device in order to store standalone images and data. The control
circuit board in the mobile CCTV also has a remote ability to control the whole mobile system and can control CCTV cameras individually. As for the fitted CCTV, this will be controlled by the main control circuit board connected directly with the main circuit board of the alarm system.

The remote control system can be transformed into a robotic system to run specific tasks where upgrading is achievable with extra features installed onto the mobile CCTV system. For example, if a pair of robotic arms is fitted to the system it will have the ability to move objects. This might be useful in hazardous areas such as where there may be a risk of exposure to radiation or high temperatures.

**Demonstrator Development Activities**

**Repurposing of Mobile Phones**

A key aim of the REPURPEL project was to investigate potential practical applications for repurposed electronics and to attempt to show proof of concept by building an actual demonstrator unit. Early on in the project it was clear that smart mobile phones offered the best potential for use in the demonstrators because of the their wide range of features, interface options and availability.

Having decided to use end of life mobile phones as the basis for the demonstrator, important objectives were to examine and consider the following;

1. the hardware features of various mobile phones
2. the software development requirements for repurposing the mobile phone
3. the possible repurposing applications in which mobile phones could be used
4. implementation of a suitable application to demonstrate the potential of mobile phone repurposing.

Hardware Features

The specific hardware features of mobile phones obviously vary significantly from manufacturer to manufacturer and so, depending on the repurposing application, some phones will be more suitable than others. For example, phones vary widely in the processor used, the amount and types of memory and the number and types of interfaces with which an external connection can be made.

For many repurposing applications there will be a requirement to interface the mobile phone to other electronic devices such as monitoring and sensing equipment. There are two basic approaches to implementing a data connection to the mobile phone; a direct electrical connection through a wired connection or via wireless.

Within each of these approaches there are several options and in the case of a direct electrical connection the options include;

- a physical connection to the hardware circuit board of the mobile phone.

- a physical interface circuit provided on the mobile phone through a standard connector. e.g. the Nokia Pop-Port

- a standard physical interface such as a Universal Serial Bus (USB)

From an electronic point of view the direct interface method is the easiest and simplest to implement. Considering each of the above direct wired connections in turn:

a) this type of interface requires considerable knowledge of the circuit layout and function of the mobile phone’s electronics. It is unlikely that this
proprietary information will be available and also, the interface would be specific to a particular manufacturer and maybe even to a specific model. For these reasons this interfacing method was not considered further in the development of the demonstrator units, although it could be a viable route if the original equipment manufacturer is willing to become involved in the repurposing of their products.

b) a standard physical interface, often providing simple serial data I/O is available on many mobile phones along with some information of the function or operation of the interface. This initially appears to be a simple and effective way of allowing the interfacing of a mobile phone to other electronic circuit.

c) The USB connection is well documented and is a standardised interface. However, as far as it can be ascertained, none of the current USB interfaces on mobile phones implement the host features of USB and therefore would require the device that is to be interfaced to the mobile phone to implement the USB host features. Currently, this means something like a PC, laptop or similarly powerful processing platform. This would imply that, in this configuration, the mobile phone would become a peripheral unit in the interface and not the main processing platform, which to some extent negates the concept of using the mobile phone as the main computing platform in the repurposed application. For this reason the USB interface was not considered further. However, it could be that, in the future, mobile phones will implement the host USB features. It is also possible that certain specific repurposing applications may use several mobile phones in conjunction with a PC or similar device, in a more complex or computationally demanding application. Hence, although this approach was not adopted for the demonstrator unit, it could be worth further investigation for certain applications.

In terms of wireless interfaces there are also several possibilities that could be used depending on the application and type of mobile phone. These include;
• SMS/MMS
• Bluetooth
• Infra Red
• GSM – Speech
• Wi-Fi

All of the above are standard wireless connections with well defined protocols, and thus these would appear to provide a promising variety of interface methods accessing the mobile phone’s capabilities. However, this would require that the device being interfaced had the equivalent wireless capability which would add complexity to the device and also additional cost. (It should be noted that as these technologies become more common, their associated costs are reducing).

Based on a more detailed analysis of the considerations listed above, a decision was made that this project would examine the use of the following interfaces:

• Nokia Pop-Port
• USB
• Bluetooth
• SMS/MMS
• Wi-fi

With the exception of the Nokia Pop-Port all of the interfaces were successfully employed in a variety of applications. (Detailed information on the Nokia Pop-Port was difficult to find and, although interface circuits were built and software developed, reliable communication was not achieved).
Operating system software and application development

Another important factor that needs to be considered when repurposing mobile phones is the type of operating system it uses and the associated software development facilities available. As mentioned earlier in the report, with current mobile phones there are two prevalent operating systems; Symbian OS and Windows Mobile. Symbian OS was developed specifically for mobile phone applications and provides targeted support for mobile phones and their unique capabilities, whereas Windows Mobile is really the Windows OS modified and trimmed down (some might argue shoe-horned) for mobile applications. Both operating systems have good development tools but on balance it was felt that for the preparation of the demonstrator units, Symbian OS would be most appropriate. (See appendix A). Many programming languages could have been used but C++ was chosen as this was widely available, optimal for most applications and the developers were experienced in the language.

There is a vast amount of information that needs to be assimilated and learned in order to be able to use all the features and capabilities of modern mobile phones. In terms of the software, there is the actual OS and all of its associated libraries. These libraries of Application Program Interfaces (APIs) provide the software interface between the user application and the operating system, which in turn accesses the associated hardware. This wealth of information leads to a steep learning curve and requires knowledgeable and skilled software engineers who ideally require some knowledge of the underlying electronic technology.

Applications

The initial applications considered for repurposed mobile phones were in the area of monitoring and possibly some additional form of simple control. For example, a sensor could be interfaced to a repurposed mobile phone and the physical parameter being sensed could be measured and monitored either locally on the mobile phone display and/or with the possibility of wirelessly communicating the information to other devices. In other words, the mobile phone would be used in conjunction with other electronic devices through one of the interfaces described
earlier. However, it is also possible to conceive of other applications where just the features of the mobile phone alone could be used.

With this in mind several application scenarios were developed:

a) Sending a SMS text message when an electrical contact is made i.e. some type of sensing activity could be used to detect a change in a given parameter and the phone would send an appropriate text message.

b) Home monitoring and control. This application interfaced a Zigbee* Home network to a mobile phone via a Bluetooth-to-serial dongle allowing SMS messages to be sent and received. The SMS messages received allowed control of the Zigbee home network and the transmitted SMS messages provided a remote monitoring capability.

c) Control of a mobile robot using the mobile phone keypad to send Bluetooth control commands to a mobile robot over a Zigbee network.

d) Using the camera of the mobile connected via USB to a PC to provide a web-camera

e) A voice controlled password security system.

Each of the above applications is described in more detail in the appendices at the end of this report.

*(ZigBee is the name of a specification for a suite of high level communication protocols using small, low-power digital radios based on the IEEE 802.15.4
standard for wireless personal area networks (WPANs). The technology is intended to be simpler and cheaper than other WPANs, such as Bluetooth. ZigBee is used in radio-frequency applications that require a low data rate, long battery life and secure networking.)

**Summary of demonstrator development**

This project has successfully developed applications that make use of many of the features and capabilities of mobile phones. One problem that has been identified is the interfacing of external electronic devices to the computing capability of the mobile phone. A direct interface would seem to be the simplest but, with the exception of USB, is often specific to a particular manufacturer. Also, these direct interfaces seem to be disappearing on the latest mobile phone models. USB currently has its limitations in that it cannot support host commands. However the USB interface can be used with PCs and laptops where the mobile phone, instead of being the dominant computing element in the system, becomes a peripheral to a more powerful system.

With the exception of USB and the limitations it imposes, wireless connection would seem the way to proceed. This does require additional hardware on the device being interfaced but as these wireless technologies become ever more commonplace their cost and ease of use will enable them to be used in more applications.

The software development is also non-trivial; there is a steep learning curve and mastering the operating system and the vast libraries of API’s is not straightforward. However, the range of possible applications is huge and limited only by ones imagination. As to which specific applications are practical and viable, only a more detailed individual analysis will reveal. The short feasibility study has however clearly demonstrated the technical viability of repurposing end of life electronic devices.

Various interactivity elements have been developed that could be combined in different ways depending on the application. These include making use of the inherent features found in mobile phone such as SMS, image capture, Bluetooth, Wi-Fi as well as speech recognition. A demonstrator model has also been built which
uses a repurposed mobile phone as the central control unit for a home monitoring and control system. This unit enables someone remote from the property to examine the status of their property eg lights, temperature, presence of intruders etc and to take appropriate action such as locking/unlocking doors, turning lights on and off and adjusting the central heating.

The Home Automation Demonstrator
This demonstrator uses a repurposed mobile phone (bottom left) to monitor and control activities within the home. In this case they are heating (top left), lighting (bottom right) and activities relating to the arrival of a visitor who rings the door bell (bottom left). Information is sent to the user's phone (bottom right), who can then implement the necessary action, such as opening the entrance gate (bottom centre to admit the visitor). Security elements such as use of a password and/or voice recognition are also employed.
Future Work

This short feasibility study has focussed on the development of basic demonstrator units that were capable of showing the proof of concept of repurposing. To that end the project has achieved its objectives very successfully. However, it is acknowledged that this demonstration is just the first step on the road to the practical and volume implementation of electronics repurposing in ‘real world’ applications.

The team at aXr Ltd are fully committed to building on the success of this feasibility study and are currently investigating ways of securing additional support funding for a multi-partner project to develop a repurposed mobile phone base unit for a specific application. To this end a potential end-user partner with an innovative, yet currently confidential, monitoring application has been identified, although at the request of the potential partner company, the specific details cannot be revealed at this stage.

Preliminary discussions have also been held with the Environmental Knowledge Transfer Network’s EuroEnviron Manager. There is a new pan-European funding programme entitled ‘Eurostars’ that the UK has just joined. It is being run by EUREKA and funding is aimed at ‘R&D active SMEs and funding is available for up to 50% of the cost of a project. The next call closes on 21st November. More details are available at the Eurostars website, which can be found at www.eurostars-eureka.eu. Following on from the REPURPEL project, a meeting is planned with the KTN to explore the possibilities for this type of project and support in more detail.

Some of the key activities that will be necessary following on from the completion of this project include;

- determining the best way to protect the intellectual property that has been developed in the project

- manufacture of a robust and easily transportable demonstrator system that can be used to publicise the successful outcomes of this project and to help raise the level of interest in potential collaborative partners for future work

- publicise the results of the work carried out during the project and disseminate the results

- seek additional potential partners for further collaborative work.
Summary and Conclusions

This short feasibility study has addressed the subject of electronics repurposing as a potential route, both for preventing large quantities of redundant electronic equipment being subjected to basic recycling processes or being consigned to landfill, and for replacing demand for new electronic assemblies with existing modified products that have a similar service life. The work carried out has addressed a number of the key considerations around the possibilities for electronics repurposing both from a theoretical and practical perspective. A large part of the study’s activity has been focussed on the development of practical exemplar demonstrator units. By undertaking suitable software and hardware modifications to suitable smart mobile phones, the practical repurposing of electronic devices has been clearly demonstrated. Specifically, end of life mobile phones have been repurposed to communicate both with sensors and monitoring devices, as well as with other mobile phones. This scenario simulates the use of repurposed mobile phones for the remote monitoring and control of defined activities such as would be required in security systems.

In addition to the development of an in-vivo practical demonstrator system, other potential applications have also been defined. The work has also considered the potential advantages and disadvantages of repurposing in the context of other possible end of life scenarios.

The clear conclusion from this work is that the repurposing of sophisticated electronic devices such as mobile phones is indeed practically possible and may be suitable for use in a number of applications. There are, however, a number of important issues that could influence the likelihood of a phone or similar device being repurposed and these will need to be considered in detail for each specific potential application.

During the project aXr Ltd has been contacted by a company interested in using repurposed mobile phones for a specific but currently confidential application. It is the intention of aXr to work with this company to take the concept of electronics repurposing forward to a practical application.
Acknowledgement
The authors would like to thank Alan Goude, Jee Heng Sia and Rajesh V.
Gottumukkala for their contribution to this project and in particular for their
development of the demonstrator modules.

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E9C8B63&sec=&spon=&amp;pagewanted=print)
## Appendix A – Main Operating Systems for Mobile Phones

### Comparison of Windows Mobile OS and Symbian OS

<table>
<thead>
<tr>
<th>#</th>
<th>Windows Mobile</th>
<th>Symbian OS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Developed by Microsoft, targeting, Pocket PC’s, Smart Phones, and Portable Media Centres</td>
<td>Developed by Symbian Ltd, targeting; Mobile Phones</td>
</tr>
<tr>
<td>4</td>
<td>Visual Studio.Net 2005 is licensed (required for Std SDK 6.0)</td>
<td>All SDK’s (Except Visual Studio.Net 2005 IDE) are free</td>
</tr>
<tr>
<td>5</td>
<td>Languages – Visual C#, Visual C++</td>
<td>Languages – C++, Java, also C and Python.</td>
</tr>
<tr>
<td>6</td>
<td>No clean up stack</td>
<td>Clean up stack required to release Memory</td>
</tr>
<tr>
<td>7</td>
<td>Battery life is not good</td>
<td>Good Battery Life</td>
</tr>
<tr>
<td>8</td>
<td>No stronghold in Cell Phone Market</td>
<td>Has stronghold in Cell Phone Market</td>
</tr>
<tr>
<td>9</td>
<td>Easy to use.</td>
<td>Easy to use.</td>
</tr>
<tr>
<td>10</td>
<td>Good Development Support</td>
<td>Good Development Support</td>
</tr>
<tr>
<td>11</td>
<td>Promoted by Microsoft</td>
<td>Promoted by Nokia, Ericsson, Sony Ericsson, Panasonic, Siemens</td>
</tr>
</tbody>
</table>
# Further Pros and Cons of the Symbian Operating System

<table>
<thead>
<tr>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Software development</strong></td>
<td><strong>Programming</strong></td>
</tr>
<tr>
<td>• C++ e-learning available</td>
<td>• Clean-up stack is needed to release memory</td>
</tr>
<tr>
<td>• SDK for different platforms are available. For example, series 40 platform SDKs, series 60 platform SDKs and series 80 platform SDKs</td>
<td></td>
</tr>
<tr>
<td>• Document provides an introduction to the main aspects of the S60 platform from the developer's point of view. It covers all platform editions, available tools, and guides to finding further information</td>
<td></td>
</tr>
<tr>
<td>• Tutorial and white paper are available for Carbide Development Tools for Symbian OS C++. Carbide.C++ Express is free of charge</td>
<td></td>
</tr>
<tr>
<td>• Plenty of books regarding programming Symbian OS are available</td>
<td></td>
</tr>
<tr>
<td>• Forum for discussing problem for Symbian OS programming are available</td>
<td></td>
</tr>
<tr>
<td><strong>Pc connectivity</strong></td>
<td></td>
</tr>
<tr>
<td>• Synchronizing personal information with a PC via cable or Bluetooth is possible.</td>
<td></td>
</tr>
<tr>
<td><strong>Worldwide market</strong></td>
<td><strong>Worldwide market</strong></td>
</tr>
<tr>
<td>• Symbian is the market leader, running on 100 million Smartphone worldwide. It's the most network-friendly of the bunch, able to switch among Wi-Fi, 3G, and 2.5G networks, depending on user preferences</td>
<td>• Less used in United States (Window and Blackberry dominate)</td>
</tr>
<tr>
<td>• Written in C++, the Symbian OS has a &quot;plug-in&quot; architecture, making it easier for manufacturers to add technology of their own</td>
<td></td>
</tr>
<tr>
<td>• Can be licensed by any manufacturer, and its APIs are publicly available. That translates</td>
<td></td>
</tr>
<tr>
<td><strong>into more options for IT departments</strong></td>
<td></td>
</tr>
<tr>
<td>----------------------------------------</td>
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</tbody>
</table>

### OS features
- strong telephone, messaging and browser integration
- Weak sync and media streaming capabilities.

### Battery life
- Longer battery life

### Networking & Comms
- Bluetooth v2.0 (L2CAP, RFCOMM, SDP, GAP and SPP) plus profile support
- Bluetooth stereo headset support
- USB v2.0 High Speed (Mass storage, ACM,WHCM) and USB On-The-Go support
- WLAN
- IrDA & serial
- OBEX over Bluetooth, IrDA and USB
- TCP, IPv4, IPv6, MSCHAP v2, PPP
- TCP/IP plug-in framework
- HTTP plug-in framework
- HTTP 1.1
- Pipelining
- WAP push
- Connectionless WSP
- Multi-homing, NAPT

### Kernel & Hardware Services
- ARMv5, v6 and v7 support
- L2 cache support
- Defragmentation of physical RAM
- Demand paging of read-only code and data
- Hardware-dependent support for “VFP” floating point acceleration and accelerated maths functions
- High performance file server
- MMC and SD card support including media >2GB
Based on the above comparisons, the Symbian OS was chosen as being a better platform to use in the project because applications could be developed using Visual Studio.Net 2005 or the Symbian SDK. It also has greater language support, no licensed SDK’s, good battery life and a strong position in the mobile phone market.
Appendix B – Remote Home Automation

Description

Figure 1: Remote Home Automation

Figure 2: Zigbee Coordinator Module
Figure 1 shows the configuration or devices used in the remote home automation demonstrator. A minimum of two mobile phones are needed. Mobile phone 1 is used to send SMS’s to control the home appliances, for example heater, air conditioner, staircase light and bedroom light. Mobile phone 2 is used to receive SMS from the mobile phone 1 and forward the command to the Zigbee coordinator via the Bluetooth serial adapter. Mobile phone 2 is also used to send the sensor's data back to mobile phone 1 automatically by SMS when instructed to do so.

For ease of design, four Zigbee kits and a Zigbee coordinator were used to simulate the home appliances. The Zigbee coordinator is used to start the Zigbee wireless network, allow child nodes to join the network, forward the commands received from the mobile phone 2 to its child nodes or forward the sensor's data back to mobile phone 2 via the Bluetooth serial adapter.

Each Zigbee child node has its own functionality. child node 1 functions as a heater and the sensor’s data are taken from here. Child node 2 functions as an air conditioning, child node 3 functions as a staircase light and child node 4 functions as a bedroom light.

The light emitting diode (LED) of each Zigbee child node is used to indicate the condition of the devices. The message “Switch On the LED” will mean the device has been turned on (activated) and “Switch Off the LED” will mean the device has been turned off. (de-activated).

Figure 2 summarises the main technology used in this project. These are:
- SMS messaging between mobiles
- SMS messages received by mobile phone 2 are parsed and converted to Bluetooth commands which in turn are converted to serial data (RS232 format) and sent to the Zigbee kit
- Serial data from the Zigbee kit is converted to Bluetooth commands which are received by MP2 which cause SMS messages to be transmitted to MP1
**Instructions**

1. Activate the Zigbee network (home automation) and make sure all child nodes join the network
2. Switch on the Bluetooth serial adapter and connect it to the Zigbee coordinator
3. Launch the application (MyBluetoothV3) that is installed to the mobile phone 2
4. Select the option by pressing the left soft key of the phone, choose "activate Bluetooth" command to activate the Bluetooth and allow the mobile phone 2 to perform pairing with the Bluetooth serial adapter
5. Once the Bluetooth link is established, mobile phone 2 is ready to receive SMS from mobile phone 1 or transmit / receive data to the Zigbee coordinator.
6. Launch the application (SendSMS) that is installed to mobile phone 1.
7. Select the option by pressing the left soft key of the phone, choose "send sms", a new menu ‘pops up’ and then choose "Bedroom light On". An SMS to turn on the Bedroom's light is now sent to mobile phone 2.
8. Once mobile phone2 receives the SMS (command) from mobile phone 1, it will then forward the command to the Zigbee coordinator via the Bluetooth serial adapter. The Zigbee child node 4 (bedroom light) should now already turn On.
9. Select the option by pressing the left soft key of the phone, choose "send SMS", a new menu ‘pops up’ and then choose "Read sensor". An SMS to read the sensor's data is now sent to mobile phone 2.
10. Once mobile phone 2 has obtained the sensor's data from the Zigbee kit, it then forwards the data to mobile phone 1 automatically by SMS.

The time taken from sending the SMS to read the sensor's data from mobile phone 1 to mobile phone2 and receiving the sensor's data from mobile phone 2 is less than 10 second.
Appendix C – Mobile robot controllable by mobile phone keypad

In this example the mobile phone’s keypad can be used to control the movement of an object, for example to control a mobile robot or a security camera’s position.

![Diagram of mobile phone 2 connected to Bluetooth serial adapter, which is connected to Zigbee coordinator, which is connected to Zigbee based mobile robot.]

Figure 3: Zigbee base robot controllable by mobile phone

The basic operation is as follows:
- Centre (selection) key -> stop
- Arrow up key -> move forward
- Arrow down key -> move backward
- Arrow right key -> turn right
- Arrow left key -> turn left

Set up and Operation

1. Activate Zigbee coordinator, turn on the robot and make sure the robot has joined the network.
2. Switch on the Bluetooth serial adapter and connect it to the Zigbee coordinator.
3. Launch the application (MyBluetoothV3) that is installed on mobile phone 2.
4. Select the option by pressing the left soft key of the phone, choose "activate Bluetooth" command to activate the Bluetooth and allow the mobile phone 2 to perform pairing with the Bluetooth serial adapter.
5. Once the Bluetooth link is established, mobile phone 2 is now ready to instruct the robot's movement.
6. Move the robot forward by pressing the "arrow up key". Stop the robot's movement by pressing the "centre key". Turn it right by pressing the "arrow right key" and turn it left by pressing the "arrow left key".
Appendix D – Sending a SMS message when an electrical contact is made.

This is a relatively straightforward application, but one that has many potential uses. When an electrical contact, for example, the contacts of a relay or a simple switch, is made, the mobile phone will power up and send a previously prepared SMS message stored in the phone’s memory to a predefined telephone number.

Appendix E - Voice controlled password security system

This application makes use of the existing features of the mobile phone but combines them to provide a novel application. The mobile phone program is activated by pressing a key on the mobile and then the password is spoken followed by the word “done”. The mobile’s microphone captures the spoken phrase and converts it to text. The text is then compared to a stored message. If a match is found the camera of the phone takes an image which is then processed in two ways. First the program sends the image as an MMS to a predefined telephone number. Secondly the program sends the image as a file attachment to an email address (the email address is defined within the program). The email is sent using a Wi-Fi connection.

The stored password can be changed by sending an SMS to the program. This application is shown schematically below.
Voice controlled password security system

The mobile phone captures the spoken word, converts it to text and compares the text with a stored password. If there is a match an image of the speaker is captured and transmitted.
Appendix F - References specific to the demonstrator modules

1.0 Forum Nokia

1.1 Getting started


1.2 Tools and SDKs

http://www.forum.nokia.com/info/sw.nokia.com/id/4a7149a5-95a5-4726-913a-3c6f21eb65a5/S60-SDK-0616-3.0-mr.html

1.3 Symbian C++ eLearning


1.4 Bluetooth point to multi point example

http://www.forum.nokia.com/info/sw.nokia.com/id/e56fccb6-2d70-4a02-90087b3e97927057/S60_Platform_Bluetooth_Point_to_Multipoint_Example.html

1.5 SMS example

http://www.forum.nokia.com/info/sw.nokia.com/id/5f17ccde-249e-4c7d-ace9-980095ea5db1/S60_Platform_SMS_Example_v2_0_en.zip.html
2.0 Jennic Zigbee

2.1 Support or getting started


2.2 Software development


2.3 Application notes


2.4 Reference manual

http://www.jennic.com/support/view_section.php?sectionID=0000000001

2.5 Zigbee eLearning

http://www.jennic.com/elearning/ zigbee/index.htm

2.6 Zigbee Home sensor demonstration

Appendix G - Life Cycle Assessment (LCA) considerations

One of the key challenges in selecting the optimal treatment process for end of life electronics is the selection of the appropriate route for the specific type of product. For example, there are clearly very different material compositions in a mobile phone and a washing machine and thus the optimisation of the end of life processes will need to take these differences into account. Similarly, there are also likely to be significant differences in the results of any LCA approaches that consider disparate elements of the waste stream. Mobile phones, for example, are often discarded after only one year of use, yet their practical working lives may be much longer. Conversely, conventional CRT based televisions may last an average of fourteen years and have traditionally not been discarded until they reach end of life.

Mobile phones represent perhaps what is, in terms of mass and volume, one of the most valuable electronic products types currently found in large numbers in WEEE streams. The rapid introduction of new and improved technology into mobile phones coupled with increasing functionality such as cameras and music players means that they have relatively short lifecycles and are rapidly seen as obsolete by many users within little over a year. The UK has more mobile phone subscriptions than people and, as of December 2005, nearly 68 million mobile phones were active in Britain, representing 1.13 active phones for every person. There are also estimated to be more than 90 million unused mobile phones in the UK. As the sales of mobile phones in Western Europe are almost 150 million units per year, large numbers of perfectly functional mobile phones are replaced that are potentially still useable and which could easily be refurbished. According to Forum for the Future, currently in the UK, only around a quarter of unwanted phones are returned, leaving over 11 million phones each year unused or in landfill.

Considering that the number of mobile phone users is growing twice as fast in developing countries as in developed countries, there are clearly opportunities for the refurbishment and reuse of these phones to help satisfy these demands. There is firm evidence that second-hand mobiles can play a significant role in increasing the accessibility of telephony in less affluent countries and it is worth noting that Africa is the world’s fastest-growing mobile phone market. Despite less stringent
legislation impacting end of life electronics in the USA, over 3 million mobile phones were remanufactured during 2003 and the USA is considered to be more advanced than the Europe in this activity.

Nokia conducted a life cycle assessment (LCA) on mobile phones and it found that the most significant impact on the environment was the energy used in manufacturing the phone’s components and in powering the phone’s charger in standby mode. The raw materials, manufacturing of components and final product accounted for 60% of the total energy burden. The use phase accounted for approximately 30% of the total energy, while transportation was approximately 10%. In the raw materials and manufacturing phases, the electronic components dominated, while the phone charger and battery accounted for 13% of the overall energy burden. The LCA also showed that carbon dioxide emissions for an average 3G mobile phone over a two-year lifecycle were equivalent to those from using 4 to 6 litres of petrol.

In their LCA type assessments, Nokia made the following conclusions;

The component manufacturing and use phases of a mobile phone’s life cycle contribute the biggest environmental impacts

In the use phase the standby power consumption of the charger contributes the biggest environmental impact

The Printed Circuit Board, the Liquid Crystal Display and the Integrated Circuits are the components with the biggest environmental impact in the life of a mobile phone

The most important environmental issue for a mobile phone in all its life cycle phases is energy consumption.
In terms of minimising the overall environmental impact of mobile phones, the best approach would clearly be to refurbish and reuse mobile phones that have been replaced by technology-hungry consumers and to use them to supply markets where the use of more basic technology is currently deemed to be sufficient for most people. It has been estimated that extending the life of a mobile phone from one to four years can reduce the environmental impact by 40% [2].

The next best scenario would be to consider using the functionality of a mobile phone in some other application as has been investigated and demonstrated in this feasibility study. If this is not possible then there may be opportunities to recover and reuse functional components from the phone which could be used in other applications. Some time ago, it was reported by Shields Environmental that LCD displays from end of life mobile phones were being reused in products such as electronic hand held games and toys. With the vastly increased functionality of mobile phones in recent years, which now includes GPS, Bluetooth, music storage and playback as well as high resolution cameras, the devices now incorporate much more substantial levels of data storage capability i.e. memory and processing power. They also contain the components which are specific to the camera part of the phone i.e. a lens system and a charge coupled device for capturing the image. Additionally, phones also now typically have a high resolution colour displays. So-called disposable cameras are actually remanufactured and reused several times, and it is equally conceivable that the camera components of a mobile phone could be recovered and reused. Interestingly, there have been attempts to develop lower cost and simpler lens systems for mobile phones that utilise a sealed liquid system rather than the complex and bulky combination of lenses that is required for traditional zoom lenses. These use fewer materials and are thus cheaper to manufacture.

If it is not possible to reuse any of the individual components of a phone then the next level of recycling will involve the recovery of materials. Traditionally, this has tended to mean recovery of valuable metals via a smelting process with little regard being paid to the other materials such as plastics which could at least in theory be recovered and recycled for use in the compounding of ‘new’ mouldable polymers. In
terms of the polymers used in mobile phone casings, these are typically materials such as ABS/PC and could be a useful source of polymer that could be either used without blending to generate a useful 100% recycled material or which could be blended with virgin material. It is known that the physical and mechanical properties of polymers degrade during their service lives and when recycled they do not give the same performance as virgin materials. This problem can be overcome by blending with virgin material and there is work underway to develop a method whereby suitable plasticisers and additives can be added to the recyclate to improve the properties of the material so that they are similar to those of virgin material.

There have also been some new processes developed for the separation of other materials from end of life mobile phones, one such example being the so-called Creasolv process. This process has been developed by the Fraunhofer Institute in Freising, Germany and CreaCycle GmbH of Grevenroich, also in Germany. The Creasolve process is claimed to enable the economical and effective dismantling of mobile phones to give a metal rich fraction that can be treated using established metal recovery technologies and a polymer solution which can be processed to give a high quality polymer recyclate. The process appears to use a specially tailored organic solvent formulation to dissolve polymers such as ABS/PC directly from the mobile phone without the need for any mechanical comminution process such as shredding. The solution is then separated from the insoluble materials and particles of ABS/PC recovered by precipitation. It is claimed that the polymer recyclate is able to offer mechanical properties similar to those of virgin material.

For the future there is growing interest in the use of non-fossil fuel derived plastics for mobile phone cases. For example, materials such as polylactic acid (PLA), a bioplastic derived from corn, have been generating growing interest in recent years as possible replacements for conventional petroleum-based plastics. Until recently, PLA had not been used in electronic devices as it had insufficient heat resistance and strength. However, NEC and UNITIKA have jointly developed a PLA bioplastic reinforced with kenaf fiber, (kenaf is a biomass-based flexibiliser and reinforcing filler.) This new material is already being used for the entire casing of a new NTT mobile phone which was launched in Japan during March 2006. In studies carried
out in 2001, the typical material composition of a mobile phone was found to be as follows;

<table>
<thead>
<tr>
<th>Material</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABS-PC</td>
<td>29%</td>
</tr>
<tr>
<td>Ceramics</td>
<td>16%</td>
</tr>
<tr>
<td>Cu and compounds</td>
<td>15%</td>
</tr>
<tr>
<td>Silicon Plastics</td>
<td>10%</td>
</tr>
<tr>
<td>Epoxy</td>
<td>9%</td>
</tr>
<tr>
<td>Other Plastics</td>
<td>8%</td>
</tr>
<tr>
<td>Iron</td>
<td>3%</td>
</tr>
<tr>
<td>PPS</td>
<td>2%</td>
</tr>
<tr>
<td>Flame retardant</td>
<td>1%</td>
</tr>
<tr>
<td>Nickel and compounds</td>
<td>1%</td>
</tr>
<tr>
<td>Zinc and compounds</td>
<td>1%</td>
</tr>
<tr>
<td>Silver and compounds</td>
<td>1%</td>
</tr>
<tr>
<td>Al, Sn, Pb, Au, Pd, Mn, etc. less than</td>
<td>1%</td>
</tr>
<tr>
<td>Other</td>
<td>3%</td>
</tr>
</tbody>
</table>

According to data published by the University of Florida Study, the average material composition of the cell phones they tested was as follows;

- 45% plastics
- 40% printed circuit board
- 4% liquid crystal display (LCD)
- 3% magnesium plate
- 8% other metals

These figures do not include the phone batteries and also do not distinguish between
the metal composition of the ‘other metals’ section. Additional and newer information published by Nokia gives a more detailed materials breakdown for a mobile phone as follows;

### Materials content for a Specific Nokia Mobile Phone

<table>
<thead>
<tr>
<th>Material</th>
<th>Abbreviation</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermoplastic Polymer</td>
<td>ABS-PC</td>
<td>20</td>
</tr>
<tr>
<td>Copper</td>
<td>Cu</td>
<td>19</td>
</tr>
<tr>
<td>Glass</td>
<td></td>
<td>11</td>
</tr>
<tr>
<td>Aluminium</td>
<td>Al</td>
<td>9</td>
</tr>
<tr>
<td>Iron</td>
<td>Fe</td>
<td>8</td>
</tr>
<tr>
<td>Polymethylmethacrylate</td>
<td>PMMA</td>
<td>6</td>
</tr>
<tr>
<td>Silica</td>
<td>Si0₂</td>
<td>5</td>
</tr>
<tr>
<td>Thermoset Polymer</td>
<td>Epoxy</td>
<td>5</td>
</tr>
<tr>
<td>Polycarbonate</td>
<td>PC</td>
<td>4</td>
</tr>
<tr>
<td>Silicon</td>
<td>Si</td>
<td>4</td>
</tr>
<tr>
<td>Polyoxyethylene</td>
<td>POM</td>
<td>2</td>
</tr>
<tr>
<td>Polystyrene</td>
<td>PS</td>
<td>2</td>
</tr>
<tr>
<td>Brominated flame retardant</td>
<td>TBBA</td>
<td>2</td>
</tr>
<tr>
<td>Nickel</td>
<td>Ni</td>
<td>1</td>
</tr>
<tr>
<td>Tin</td>
<td>Sn</td>
<td>1</td>
</tr>
<tr>
<td>Liquid Crystal Polymer</td>
<td>LCP</td>
<td>1</td>
</tr>
</tbody>
</table>
The cumulative data for the total polymer content of a mobile phone in the above table from Nokia is in relatively close agreement with that from the University of Florida Study. However, the metals content figures vary considerably, although this is probably due to the way the phone has been broken down into its constituent parts. For example, the University of Florida Study describes the phones as being 40% printed circuit board materials, much of which will be copper.

Another earlier study on a typical mobile phone made in 2000 gave the material composition (in weight percent) as shown in the figure below. The interesting difference here compared to more recent data is the presence of 16% by weight of ceramic materials.

<table>
<thead>
<tr>
<th>Material</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plastics</td>
<td>58%</td>
</tr>
<tr>
<td>Metals</td>
<td>25%</td>
</tr>
<tr>
<td>Ceramics</td>
<td>16%</td>
</tr>
<tr>
<td>Flame retardant</td>
<td>1%</td>
</tr>
</tbody>
</table>

More recent data reported by Falconbridge Limited in 2005 gives an indication of the metal content in obsolete mobile phones. (Falconbridge is a company that recycles mobile phones for their metal content.) The company estimated that, in 1 metric tonne of obsolete mobile phones (excluding batteries), the average metal content was as follows;

<table>
<thead>
<tr>
<th>Metal</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>copper</td>
<td>140 kg</td>
</tr>
<tr>
<td>silver</td>
<td>3.14 kg</td>
</tr>
<tr>
<td>gold</td>
<td>300 g</td>
</tr>
<tr>
<td>palladium</td>
<td>130 g</td>
</tr>
<tr>
<td>platinum</td>
<td>3.00 g</td>
</tr>
</tbody>
</table>
This gives a total of slightly less than 180 kg i.e. 18% by weight of the above metals, a figure somewhat lower than the 25% reported in 2000 for older phones. However, this newer data does not include other metals such as nickel and iron which are likely to also be present.

The above information was also used to calculate the metal content and value of each of the metals for a single mobile phone weighing 113 grams and using averaged metal values for the period 2002 to 2004. The results are shown in the table below along with new values calculated using current (May 2008) metal prices;

<table>
<thead>
<tr>
<th>Metal</th>
<th>Quantity (weight/g)</th>
<th>Value ($ US) 2002 - 2004</th>
<th>Value ($ US) 2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>copper</td>
<td>16</td>
<td>0.03</td>
<td>0.13</td>
</tr>
<tr>
<td>silver</td>
<td>0.35</td>
<td>0.06</td>
<td>0.19</td>
</tr>
<tr>
<td>gold</td>
<td>0.034</td>
<td>0.40</td>
<td>0.96</td>
</tr>
<tr>
<td>palladium</td>
<td>0.015</td>
<td>0.13</td>
<td>0.21</td>
</tr>
<tr>
<td>platinum</td>
<td>0.00034</td>
<td>0.01</td>
<td>0.023</td>
</tr>
<tr>
<td>Totals</td>
<td>16.40</td>
<td>0.63</td>
<td>1.51</td>
</tr>
</tbody>
</table>

The rechargeable batteries used to power mobile phones also contain valuable materials that can be recovered and re-used. For example, the cobalt in lithium ion batteries can be recycled for use in magnetic alloys. The nickel and iron, from nickel metal hydride and nickel cadmium batteries can be used in stainless steel and the cadmium used to make new rechargeable batteries. It is worth noting that new
battery technologies are replacing traditional nickel cadmium batteries. The amount of nickel in mobile phones (excluding the battery) varies by design but increases significantly when the rechargeable batteries are included. Nickel-cadmium (containing 16-20% nickel) and nickel-metal hydride batteries (28-35% nickel) used to be the main power source for the phones, but companies have since moved toward lighter lithium-ion batteries, which only contain around 1 to 1.5% nickel.

It has been reported that between 65 and 80% of the material content of a mobile phone can be recycled and reused. However, it is also worth noting that using the plastic content of a phone as fuel enables the recovery of energy and this can increase the total recovery rate to around 90%. End of life mobile phones are typically shredded by recyclers before being transported to smelters either locally or in some cases overseas. Plastics are still considered to be of secondary importance and low value and, as yet, the infrastructure for recycling polymers has not yet been fully developed. Because of their high thermal values, most plastics are currently used as fuel although some are still land filled. The metals content of a mobile phone can be successfully recycled. The first stage of recovery is separation of the shredded metals into different fractions. Aluminum, ferrous metal and copper fractions are sold to metal refineries. PCBs are treated in a copper smelter. In the process, copper and precious metal fractions are smelted and then taken for anode casting and electrolytic refining, which separates copper from the rest of the materials. The remaining precious metal sludge containing gold, palladium and platinum is sent to precious metals plants for recovery. The metals are sold directly to customers or through metal exchanges. About 40% of the raw materials used by the metal industry are recycled materials. Metal recycling has been estimated to saves between 60 and 90% of the energy required for mining metal from ore.

From an LCA perspective it is also important to note that the weight of a typical mobile phone has decreased significantly in recent years and thus there will be major positive implications not just for the materials processing and manufacturing stages of the phone’s life cycle but also in the use phase. Early mobiles weighed almost 1 kilogramme but in recent years this has reduced significantly, so that many phones are now below 100 g (e.g. an older Nokia 6110 is 137g and the newer 8210
is 79g). Energy costs associated with the transportation of phones from the manufacturer to the end user (e.g. from the Far East to Europe and much by air freight) have been included in some analyses but consideration also needs to be given to the additional energy consumption associated with transportation during the use phase). The figure below summarises what happens to phones at end of life.

In order to improve the environmental performance, i.e. to reduce the overall burden on the environment, of mobile phones, environmental impact data needs to be available for the whole lifecycle of the device in question. This is needed so that it can be utilised at the design stage to enable design for the environment principles to be used and the design to be optimised in this context. In the case of a sophisticated device such as a mobile phone, the data from a true LCA type approach will be extremely complicated and may be too complex to yield useful information for designers without some degree of simplification. Unfortunately, and
Despite some areas of commonality in terms of data requirements, it seems that there is a real disconnect that currently prevents the integration of LCA into the design and process optimisation stages that are increasingly deemed to be so important by the electronics manufacturers and in this case, mobile phone makers. It is reported, for example, that process modelling in most of the existing LCA studies is ad hoc and that current LCA software does not have extensive physical and chemical databases nor process modules dedicated to the semiconductor industry, which clearly makes a very significant contribution to the overall mobile phone. (Manufacturing a 32MB RAM module requires 32 kg of water, 1.6 kg of fossil fuels, 700 g of gases and up to 72 g of different chemicals). Nokia concluded that full LCA, Ecological Footprint Analysis (EFA) and Material Input Per Service Unit (MIPS) approaches were (January 2005) not yet appropriate for application in the development cycle of mobile phones. More than 90% of the waste in the life cycle of a mobile phone is generated at the raw-material stage.