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Monitoring External Resources in Java MIDP

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**Abstract**

We present a Java library for mobile phones which tracks and controls at runtime the use of potentially costly resources, such as premium rate text messages. This improves on the existing framework (MIDP

— the Mobile Information Device Profile [[6](#_bookmark29)]), where for example every text message must be authorised explicitly by the user as it is sent. Our resource management library supports richer protocols, like advance reservation and bulk messaging, while maintaining the security guarantee that attempted resource abuse is trapped.

*Keywords:* Runtime Monitoring, Resource Control, Java MIDP, Security.

# Introduction

Modern mobile phones are powerful computers. Their primary task, providing mobile wireless telephone services, is comparatively losing importance as they are being used for a range of other applications, from personal information managers to web browsers, from media players to games. Most of these applications ac- cess the network [2](#_bookmark1) , either because it is integral to their functionality (e. g. web browsers, online games), or because networking is adding desired features (e. g. playing streaming media or synchronising diaries).

The cost of the standard computational resources, like execution time or memory space, is determined solely by the computational device (i. e. the hardware of the mobile phone) itself. The cost of network access, however, is determined by external entities, e. g. the business model of the phone operator, which is why we classify network access as an *external resource*. Moreover, it is a resource the spending of which users generally would like to control tightly because it costs them money.

1 Email: [pmaier@inf.ed.ac.uk](mailto:pmaier@inf.ed.ac.uk)

2 Refers to the operator’s mobile phone network; access to other networks (like the Internet) is routed through this one.

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create msg1

send(msg1)

Is it ok to send 1 msg to +44 444 1234567 ?

NO

YES

send to +44 444 1234567

create msg2

send(msg2)

Is it ok to send 1 msg to +33 333 7654321 ?

NO

YES

send to +33 333 7654321

create msg3

send(msg3)

Is it ok to send 1 msg to +44 444 1234567 ?

NO

YES

send to +44 444 1234567

**SecurityException**



create multiset enable(multiset) How many msgs to send ? of phone nums To +44 444 1234567

To +33 333 7654321

2

1

0

1

0

NO all nums return mgr

granted to (containing submultiset of granted nums) mgr ?

YES

create msg1

send(mgr, msg1)

send to +44 444 1234567

create msg2

send(mgr, msg2)

send to +33 333 7654321

create msg3

send(mgr, msg3)

send to +44 444 1234567

Fig. 1. Transaction sending 3 text messages; in MIDP 2.0 (left) and with explicit resource management (right).

The last point actually goes double: If network access is maliciously exploited it could be very expensive, but even if it is not exploited, users care about each 10p [3](#_bookmark3) ,

i. e. they want to know the exact cost beforehand.

In MIDP [[6](#_bookmark29)], the current standard framework for Java applications on mobile phones, monitoring external resources, like communication via text message, is left to the user, as illustrated by the flowchart on the left hand side of Figure [1](#_bookmark2). For each of the three messages, the application pauses to ask the user for authorisation before sending. This one-shot authorisation is clearly prohibitive for applications wishing to send many messages because users will get annoyed by the many pop-up screens, which malicious applications may exploit to trick users into authorising messages to premium rate numbers. Such social engineering attacks [[12](#_bookmark35)] have been reported in the wild [[14](#_bookmark37)]. Yet, even if an application sends only few messages, one- shot authorisation can lead to undesirable results, like transactions aborted midway by an exception because the user stops authorising messages (see the left hand side of Figure [1](#_bookmark2)).

We propose explicit accounting and monitoring of external resources to better protect the user from accidental or malicious resource abuse. Our approach revolves around *resource manager* objects, which keep an account of which external resources an application is granted to use and how often. The right hand side of Figure [1](#_bookmark2) illustrates this on the messaging example. Before sending messages, the application computes a multiset of phone numbers encoding how many messages it will send to which recipients. In a single authorisation dialogue the user then gets to decide how many messages the applications may send to whom. This information (a sub- multiset of the multiset of requested numbers) is stored in a resource manager. The application only proceeds if all the requested numbers have actually been granted,

3 The standard cost of sending a text message in the United Kingdom.

in which case it calls instrumented methods for sending the messages, taking an extra resource manager argument, which monitors the resources being spent (and would abort the application if it was overspending).

Explicit resource management has additional benefits besides runtime monitor- ing. It forces the application to determine early on how many resources to request. It provides a clear user interface by centralising the choice of which of the requested resource to grant into a single dialogue. Plus, it enables the application to react flexibly to the amount of resources it has been granted, i. e. the application can choose whether it is feasible to continue with the resources granted or whether it has to abort because of insufficient resources.

The rest of this paper is structured as follows. Section [2](#_bookmark4) gathers some facts about MIDP which are relevant to us. Section [3](#_bookmark6) introduces the resource management library, which Section [4](#_bookmark12) extends by adding policies. Section [5](#_bookmark14) describes the security properties that library guarantees and outlines a deployment scenario. Section [6](#_bookmark22) discusses related work, and Section [7](#_bookmark23) concludes.

# Background: The MIDP Security Model

The *Mobile Information Device Proﬁle* (MIDP, current version 2.0 [[6](#_bookmark29)]) is the current standard framework for Java applets (also called *MIDlets*) on networked mobile devices. MIDP builds upon the *Connected Limited Device Conﬁguration* (CLDC, current version 1.1 [[7](#_bookmark30)]). Together, CLDC and MIDP, which are part of the *Java Micro Edition Platform* (Java ME), define a set of APIs for programming small devices like phones and PDAs. With security in mind, they restrict Java in several ways. In particular, reflection and custom class loading are not supported; all of a MIDlet’s classes must be loaded from a single JAR using the standard CLDC class loader, which renders possible to statically check the MIDlet’s classes for certain properties (see Section [5.4](#_bookmark20)).

As of MIDP 2.0, access to sensitive APIs and functions (e. g. for sending text messages) is regulated by a permission-based security model. MIDlets are bound to *protection domains* based on whether and by whom they are signed (where a signa- ture expresses the signer’s trust in the MIDlet but does not provide any guarantees about the code itself). Each protection domain holds a set of *permissions*, each of which is either flagged as *Allowed* or *User*. The former grants unconditional access whereas the latter requires access to be authorised by the user. How often this authorisation has to be obtained depends on whether a *User* permission is flagged as *Blanket*, *Session* or *OneShot* ; the latter requires authorisation for every single access.

According to the MIDP specification, only MIDlets signed by the device manu- facturer or the network operator may obtain unconditional access to cost-sensitive functions (e. g. for sending text messages). The protection domains for other MI- Dlets must insist on OneShot authorisation for access to these functions. As a con- sequence, MIDlets wishing to use messaging more than just occasionally are faced with the choice of either having to be signed by the operator (or manufacturer) or

\* \* 1 0..1

**ResManager**



***Resource***

**MsgResource**

|  |  |
| --- | --- |
| **ResMultiset** |  |
|  |  |
| + isEmpty() : boolean  + contains(ResMultiset) : boolean  + clear()  + insert(Resource, int)  + remove(Resource, int)  + add(ResMultiset)  + subtract(ResMultiset)  + union(ResMultiset)  + intersect(ResMultiset)  + split(ResMultiset) : ResMultiset |

<<throw>>

**java.lang.Error**

**ResManagerError**

+ enable(ResMultiset)

+ clear()

+ join(ResManager)

+ split(ResMultiset) : ResManager

+ assertEmpty()

+ assertAtLeast(ResMultiset)

Fig. 2. UML class diagram of the basic resource management API. All terminal (w. r. t. generalisation) classes are final.

having to annoy their users with lots of authorisation screens.

# Basic Resource Management API

This section presents an API for monitoring the use of external resources. The API introduces special objects, called *resource managers*, which encapsulate multisets of resources that a MIDlet may legally use (according to the user’s approval) and which are passed as arguments into instrumented MIDP methods that actually use the resources. These methods, e. g. the method for sending text messages, check the resource manager before consuming the resources. If the required resources are not present, the instrumented methods abort the MIDlet with a runtime error.

* 1. *Resource Managers*

Figure [2](#_bookmark5) shows a class diagram of resource management package. The core of the API is the final class ResManager, which encapsulates a multiset of resources and whose methods are explained below. The final class ResMultiset provides modifiable multisets of resources, with the usual operations on multisets, includ- ing multiset intersection, sum and inclusion. Internally, multisets are realised by hash tables, mapping resources to multiplicities (which may be infinite). Every ResMultiset object encapsulates its mutable state, so that it cannot be changed other than by calling its public methods. The abstract class Resource serves as an abstract type for resources; actual resources (e. g. the class MsgResource rep- resenting the permission to send one text message to a given phone number) must be final subclasses. Being used as keys in hash tables, resources must abide by the following contract: They must be immutable objects, and resources constructed from the same arguments must be indistinguishable by the equals method.

The class ResManager encapsulates a multiset of resources via a private field rs of type ResMultiset. All public methods are synchronised to avoid races in case different threads access the same resource manager. The table below lists the methods with a JML-style [4](#_bookmark7) semantics, where the symbols *⊆*,and *∩* stand for multiset inclusion, sum and intersection, respectively.

4 The \operators generally bear the same meaning as in JML [[11](#_bookmark34)], except that \old(e) refers to the pre-state of expression e in the *pre*-state of the heap.

|  |  |  |  |
| --- | --- | --- | --- |
|  | **requires** | **ensures** | **modifies** |
| **ResManager()** | *true* | this.rs = *∅* | this.rs |
| **void enable(ResMultiset req)** | *true* | this.rsreq = *\*old(this.rs) *\*old(req) *∧*  req *⊆ \*old(req) | this.rs, req |
| **void clear()** | *true* | this.rs = *∅* | this.rs |
| **void join(ResManager mgr)** | *true* | this.rs = *\*old(this.rs) *\*old(mgr.rs) *∧*  mgr.rs = *∅* | this.rs, mgr.rs |
| **ResManager split(ResMultiset bound)** | *true* | *\*fresh(*\*result) *∧*  *\*result.rs = *\*old(this.rs) *∩* bound *∧*  *\*result.rsthis.rs = *\*old(this.rs) | this.rs |
| **void assertEmpty()** | this.rs = *∅* | *true* | *\*nothing |
| **void assertAtLeast(ResMultiset bound)** | bound *⊆* this.rs | *true* | *\*nothing |

The enable method takes a multiset req of requested resources and lets the user decide (in a pop-up dialogue) how many of these resources to add to the manager’s multiset rs. As a side effect, enable modifies its argument req; upon return from enable, the MIDlet should check req to learn which of the requested resources it is being denied; in particular, if req is empty then all of the requested resources have been granted.

The methods clear, split and join provide some control over the contents of a resource manager, by consuming all its resources, transferring some resources to a new manager, or joining the resources in two managers, respectively. Thanks to split and join, the MIDlet may keep resource managers thread local, avoiding contention over shared managers.

The assertion methods check whether their preconditions hold. If so they behave like no-ops, otherwise they throw an instance of ResManagerError. The latter case must be seen as a violation of the MIDlet’s own logic (much like failing an assertion), and the MIDlet should not be allowed attempts at repairing the situation (by catching the error), which is why ResManagerError extends java.lang.Error rather than java.lang.Exception.

* 1. *Example: Bulk Messaging MIDlet*

We illustrate the use of resource managers by an example application built on top of the *Wireless Messaging API* (WMA, current version 2.0 [[8](#_bookmark31)]), a bulk messaging MIDlet, which lets the user send a text message to a group of recipients from his phone book. Figure [3](#_bookmark8) (left column) shows the MIDlet’s method that actually sends the message. The method takes an (already open) message connection, a message and a group of recipients (represented as array of phone book entries). First, the MIDlet builds up a multiset of resources rs by iterating over the group of recipients and for each one, extracting the mobile phone number, converting it into a resource by constructing an instance of MsgResource, and adding one occurrence of that instance to the multiset. Next, the MIDlet creates an empty resource manager mgr and enables it to use the resources in the multiset rs. This will pop up a confirmation dialogue box where the user can approve or deny the planned resource usage, modifying rs as a side effect. Only if the user approves of all messages to be sent, i. e. if enable returns its argument rs empty, does the code proceed to

void sendBulk(MessageConnection conn,

Message msg, PhonebookEntry[] grp)

{

ResMultiset rs = new ResMultiset(); for (int i=0; i < grp.length; i++) {

String num = grp[i].getMobileNum(); rs.insert(new MsgResource(num), 1);

}

ResManager mgr = new ResManager(); mgr.enable(rs);

if (rs.isEmpty()) {

for (int i=0; i < grp.length; i++) { String num = grp[i].getMobileNum(); msg.setAddress(num);

conn.send(mgr, msg);

}

mgr.assertEmpty();

}

else mgr.clear();

}

public void send(ResManager mgr, Message msg) throws IOException, InterruptedIOException

{

synchorized (msg) {

String num = msg.getAddress(); ResMultiset rs = new ResMultiset(); rs.insert(new MsgResource(num), 1);

ResManager local\_mgr = mgr.split(rs); local\_mgr.assertAtLeast(rs);

try {

send(msg);

local\_mgr.clear(); local\_mgr = null;

} catch (InterruptedIOException e) { local\_mgr.clear(); local\_mgr = null; throw e;

} catch (IOException e) { mgr.join(local\_mgr); local\_mgr = null; throw e;

}

}

}

Fig. 3. Bulk messaging example, left: MIDlet code, right: instrumented MIDP method.

the actual send loop. The send loop again iterates over the group of recipients, extracting for each one the mobile phone number, setting the address field of the message and sending the message using the instrumented send method, see below. After the loop, assertEmpty checks that the resource manager mgr is really empty,

i. e. all enabled resources have been used. (Instead of checking, the manager could have been cleared explicitly, like in the else branch, to prevent unintended later use of left-over resources.)

* 1. *Instrumented Methods*

Resources are consumed by specific methods, e. g. in the case of messaging by the method send(Message) declared in the WMA interface MessageConnection. To monitor whether these methods consume only resources that have been granted, we wrap them with instrumentation code checking whether a given resource manager holds the required resources. These instrumented methods are declared in sub- packages of the resource management package.

To instrument messaging, we have to augment MIDP and WMA in three places. We supplement the WMA interface MessageConnection with a new wrapper method send(ResManager,Message), provide a class which implements this extended in- terface, and revise the MIDP method Connector.open to return the new class.

The code for the wrapper method is shown on the right-hand side of Figure [3](#_bookmark8). It extracts the phone number num from the message and constructs a multiset rs containing a single occurrence of the resource corresponding to num. Then it splits the resources in rs off from the resource manager mgr and stores them in the new local resource manager local\_mgr, which is checked for containing at least the resources in rs. If this check fails a ResManagerError will be thrown, aborting the calling MIDlet; if the check succeeds we know that local\_mgr holds exactly the resources in rs. Finally, the message is actually sent by calling the uninstrumented

send method. [5](#_bookmark10) Clearing local\_mgr and nulling the reference afterwards is not strictly necessary but considered good practise; it signals that the resources in the local manager are now used up and that the manager itself is ready to be reclaimed by garbage collection.

In case of a send failure, the event that actually spends the resources (i. e. deliv- ering the text message to the operator’s network) may or may not have happened yet. We assume that an IOException is thrown before actually sending the message (e. g. because the connection to the operator’s network is down), so the resources are not yet consumed, and the handler can return them to the caller (by join- ing the local manager to mgr) before propagating the exception. However, if an InterruptedIOException is raised, we do not know whether the send event has al- ready happened, so we assume that the resources are already spent. In this case, the handler consumes the resources (by clearing the local manager) before propagating the exception.

Note that the instrumented send method method must synchronise on msg, which is accessed twice, but there is no need to synchronise on mgr (for there are no data dependencies between the first and second access) or on this (for it is accessed only once).

* 1. *Runtime Overhead*

Monitoring of external resources does cause some runtime overhead. In terms of execution time, the overhead is negligible, as very little time is spent on the in- strumentation compared to what is spent on actually consuming the resource (e. g. transmitting a message). Due to the hash table based implementation of multisets, all operations on resource managers take (at most) linear time w. r. t. to the size of the multisets involved. In fact, the overhead of the instrumented send method in Figure [3](#_bookmark8) is constant because the argument of assertAtLeast is a singleton multiset. In terms of memory, the overhead may be more severe, particularly on small de- vices, because of the memory requirements of the hash tables. Additionally, resource monitoring puts a higher strain on garbage collection because the instrumentation code temporarily allocates resources, multisets and managers. If runtime checking is not necessary or desired, it can be switched off by “erasing” resource managers

(see Section [5.2](#_bookmark18)), which reduces the memory overhead significantly.

* 1. *Extensibility*

By design, the resource management API is extensible. Monitoring new resources (e. g. the number of bytes sent over a TCP/IP connection, or the space available in the persistent record store) simply amounts to adding new resource types plus adding the appropriate instrumentation. New resource types are added by extend- ing the abstract class Resource with final subclasses, which abide by the contract

5 Depending on the MIDlet’s protection domain, the uninstrumented send method may again ask the user to authorise sending the message; Section [5.4](#_bookmark20) addresses this shortfall.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | | | |  | | | |
|  |  |  |  |  |  |  |  |
| **MsgUserPolicy** | | **MsgNationalPolicy** | | **MsgPhonebookPolicy** | |
| + getPolicy(MIDlet) : MsgUserPolicy | | + getPolicy() : MsgNationalPolicy | | + getPolicy() : MsgPhonebookPolicy | |

Fig. 4. UML class diagram of policy extension of resource management API. All terminal classes are final.

<<call>>

*~ decide(ResMultiset) : ResMultiset*

+ enable(Policy, ResMultiset)

+ clear()

+ join(ResManager)

+ split(ResMultiset) : ResManager

+ assertEmpty()

+ assertAtLeast(ResMultiset)

**ResManager**

***Policy***

on resources. Instrumented methods, which monitor the new resources before call- ing the corresponding uninstrumented methods, are added to sub-packages of the resource management package.

# Extending the API with Flexible Policies

So far, the enable method involves the user, who is selecting to-be-added resources in a pop-up dialogue. That is, the user is acting as a *policy oracle* deciding which resources to grant and which to deny. In this section, we extend the API to include more flexible policy oracles, not just the user.

* 1. *Changes to the API*

Figure [4](#_bookmark11) shows the class diagram of the extension. It adds an abstract class Policy providing an abstract, package private method decide for deciding which resources to grant and which to deny. The table below shows the formal, non-deterministic semantics of decide; granted resources are returned in a new multiset, denied re- sources are returned via the modified argument.

|  |  |  |  |
| --- | --- | --- | --- |
|  | **requires** | **ensures** | **modifies** |
| **ResMultiset decide(ResMultiset req)** | *true* | *\*fresh(*\*result) *∧ \*old(req) = req *\*result | req |

Actual policies must be final subclasses of Policy and must provide a package private implementation of decide. The latter requirement ensures that decide can be called by the resource management library only, not directly by MIDlets themselves. For a MIDlet to gain access to policies, each subclass of Policy provides a static getPolicy method which hands out the requested policy (i. e. an instance of the respective class) or null if the calling MIDlet is not authorised to use the requested policy.

MIDlets can only pass policies as arguments to other methods, in particular to the enable method of class ResManager, which consults its policy argument as an oracle to decide which resources to grant and which to deny, and which interprets a null argument as the deny-all policy, see the implementation below. Note that enable defers synchronisation on this as long as possible (i. e. until accessing the manager’s encapsulated multiset rs) to avoid locking the manager during a call to decide, which may block for a long time (e. g. if the policy consults the user).

public void enable(Policy p, ResMultiset req) {

if (p == null) return; synchronized (req) {

ResMultiset granted = p.decide(req); synchronized (this) { rs.add(granted); }

}

}

* 1. *Use of Policies in MIDlets*

The basic resource management API knew only one implicit policy: ask the user. Yet, typically each resource type has its own policy or policies. The policies for MsgResource include a MsgUserPolicy, which behaves like the implicit policy of the basic API, asking the user how many messages to send to which phone numbers. To use this policy, the call mgr.enable(rs) in the bulk messaging MIDlet (Figure [3](#_bookmark8)) must be replaced by mgr.enable(MsgUserPolicy.getPolicy(this), rs). [6](#_bookmark15)

There could be other policies for MsgResource, e. g. a MsgNationalPolicy, which grants only messages to national phone numbers. This policy could be com- bined with MsgUserPolicy by chaining calls to enable as in the following code snippet.

mgr.enable(MsgNationalPolicy.getPolicy(), rs); mgr.enable(MsgUserPolicy.getPolicy(this), rs);

The first call enables all requested messages to national numbers, without asking the user. The second call asks the user to authorise the messages to the remaining (international) numbers. In the end, rs contains only those international numbers that the user has denied.

Another interesting policy for messaging could be a MsgPhonebookPolicy, which automatically grants all messages to numbers in the user’s phone book. If the bulk messaging MIDlet used this policy, the user would not have to confirm anything. In return, the MIDlet could maliciously send more messages than the user intended, but only to phone numbers in the user’s phone book, not to premium rate numbers (unless the MIDlet was allowed to modify the phone book).

* 1. *Extensibility*

By design of the API, adding new policies simply amounts to extending the abstract class Policy with final subclasses, which abide by the contract on policies: No public fields and methods (in particular, decide must be package private) except the static getPolicy methods, and the implementation of decide must agree with the formal semantics as shown in the table in Section [4.1](#_bookmark13).

# Security Properties of Explicit Resource Management

This section informally summarises and motivates the security guarantees provided by the resource management API and a trusted library implementing it.

6 MsgUserPolicy.getPolicy requires an argument of type MIDlet so that the policy can access the MIDlet’s screen.

* 1. *No Abuse of Resources*

**Property 1** *MIDlets using the resource management API cannot consume more resources than granted; any attempt to do so will result in the MIDlet being aborted before the abuse happens.*

The property holds for two reasons.

* + 1. Before performing any actions, the instrumented methods, e. g. the send method from Section [3.3](#_bookmark9), check their ResManager argument for the required resources and throw a ResManagerError (which will abort the MIDlet) if there aren’t enough. If there are enough resources, the instrumentation deduces the required amount from the resource manager, even if the underlying uninstru- mented method throws an exception.
    2. The implementation of the resource management API ensures that policies can- not be bypassed. Resources may be moved back and forth between managers by the methods split and join, but there is no way to sneak new resources into the managers other than by calling enable, in which case a policy gets to decide which resources to grant and which to deny. Furthermore, the im- plementation confines the multiset held by a manager, i. e. it ensures that there are no pointers from outside a manager into its mutable state, hence a manager’s multiset cannot be modified from the outside.

Of course, the above argument assumes that the MIDlet does not bypass or subvert the resource management library itself; see Section [5.4](#_bookmark20) on how to ensure this.

* 1. *Erasure*

Tracking the use of resources with resource managers does induce some overhead, mainly in terms of the memory required for storing the multisets. On small devices, one might want to avoid this overhead if a MIDlet is known to be *resource safe*, i. e. if it cannot ever throw a ResManagerError. In this case, resource managers can be “erased”.

Erasure cannot be performed as a simple source code transformation removing all occurrences of resource managers from a MIDlet, for two reasons. First, MIDlets must be able to access resource managers in order to call the enable method, even after erasure, to let a policy decide which resources to grant. Second, resource managers may appear in conditions like (mgr1 == mgr2), from where they cannot be removed unless the condition can be evaluated statically. What can be done, however, is a “soft” erasure, which keeps the managers themselves in place but erases their multisets, resulting in very lightweight *erased* resource managers.

Soft erasure can be achieved by retaining the public interface of class ResManager but replacing its implementation with a stateless dummy implementation. More precisely, erasure removes the private field rs (storing the manager’s multiset), which turns all public methods into no-ops, except for split and enable. The latter still calls the policy and reports the denied resources back to the MIDlet, whereas the former creates a fresh (erased) manager.

**Property 2** *If a MIDlet is resource safe then erasing the resource managers does not change its observable behaviour.*

The property holds because by design of the resource management API, the value of a resource manager can only affect the values of other resource managers; it cannot affect the values of other types.

Note that an optimiser can eliminate all of the calls on erased resource managers, except calls to enable, by inlining. As a result, resource managers may become unused and can be optimised away. In fact, a clever optimiser could optimise away the entire instrumentation code from the instrumented send method in Figure [3](#_bookmark8), leaving just the call of the uninstrumented method.

* 1. *Information Flow Security*

It may seem as if resource managers could infringe information flow security. Is it not possible that sensitive data (e. g. phone numbers from the address book) leaks from a manager while it is passed from method to method? We argue that at least for resource safe MIDlets, this is not the case.

**Property 3** *If a MIDlet is resource safe then its resource managers do not leak information.*

This is a corollary of Property [2](#_bookmark19). If a MIDlet is resource safe, the resource managers can be erased without changing the MIDlet’s observable behaviour. Yet, erased resource managers are stateless, so they cannot leak information. Hence, no leakage is observable.

* 1. *Secure Deployment*

As mentioned in Section [5.1](#_bookmark16), the security guarantees do not only depend on the cor- rectness of the resource management library itself but also on the MIDlet correctly using the API (i. e. not bypassing or subverting the library).

**Property 4** *Correct use of the resource management API can be checked statically by inspecting the MIDlet’s JAR only.*

The property holds due to the restrictions imposed by CLDC and MIDP (see Sec- tion [2](#_bookmark4)), which imply that all of the MIDlet’s classes are statically known (since all classes must be loaded from a single JAR) and the signature of each method call is statically known (since reflection is not supported). Thus, the following properties of the MIDlet’s class files can be statically checked.

* The MIDlet does not bypass the instrumentation. More precisely, if the MIDlet allocates a particular resource type (e. g. MsgResource) then it does not call uninstrumented methods for consuming resources of that type (e. g. the method send(Message) declared in the WMA interface MessageConnection).
* The MIDlet does not suppress failing assertions. More precisely, it does not catch

ResManagerError or any of its superclasses.

* The MIDlet does not pass policies of its own to the enable method. More pre- cisely, none of the MIDlet’s classes extend the abstract class Policy.
* The MIDlet does not subvert the implementation of resource multisets by adding resource types of its own. [7](#_bookmark21) More precisely, none of the MIDlet’s classes extend the abstract class Resource.
* The MIDlet does not exploit non-public methods (e. g. decide) of the resource management library. More precisely, none of the MIDlet’s classes are declared to be part of the packages that constitute the resource management library.

The correctness of the resource management library itself cannot be checked easily, hence the library (including the instrumented methods) has to be trusted. Yet, as MIDP does not support the download of trusted libraries, MIDlets using the resource management API have to provide the library as part of their own JAR. To establish trust in the library, a trustworthy third party (e. g. the network operator) should vouch for it by signing the MIDlet. In detail, the deployment process should comprise the following steps.

* 1. In the MIDlet’s JAR, the signer replaces the untrusted resource management library with its own trusted implementation.
  2. The signer checks for correct use of the resource management API by checking the above properties.
  3. The signer signs and deploys the MIDlet (possibly after it passed other checks, too).

The signer may choose to erase resource managers by replacing the resource man- agement library with the library for erased managers (see Section [5.2](#_bookmark18)) if there is additional confidence in the MIDlet’s resource safety (where this confidence may have been gained by type checking, extended static checking, interactive verifica- tion or extensive testing). Of course, Property [1](#_bookmark17) is not guaranteed by the library for erased managers.

There is a reason, why MIDlets should be signed by the network operator (or device manufacturer) rather than just by any trusted third party. For otherwise, the MIDP specification (see Section [2](#_bookmark4)) demands that the uninstrumented methods which are called by the instrumented ones do still pop-up authorisation screens, despite the fact that the user (or the policy) has already approved all of the resources held by resource managers.

As an alternative deployment scenario, the resource management library could be integrated into future versions of MIDP. In this case, the MIDP class loader would have to check for correct use of the API, rendering unnecessary the requirement that MIDlets be signed by the network operator.

7 The hash table based implementation of multisets may fail to function correctly if resources are added that breach the contract that Java imposes on the equals and hashCode methods.

# Related Work

Runtime monitoring to increase software reliability is at the heart of the Java lan- guage [[4](#_bookmark27)] with its mandatory runtime checking of array bounds and null pointer dereferences. Several frameworks have been proposed for enhancing Java with run- time monitoring of resource consumption, for example JRes [[3](#_bookmark26)], J-Seal [[1](#_bookmark24)] and J- RAF [[10](#_bookmark33)]. Real-time Java (RTSJ [[5](#_bookmark28)]) provides resource monitoring as part of its support for real-time applications. These frameworks monitor specific resources (CPU, memory, network bandwidth, threads), relying on instrumentation of either the JVM (for CPU time), low level system classes (for memory and network band- width) and the bytecode itself (for memory and instruction counting). Where our resource management API is designed to enforce security, these frameworks were developed to support resource aware applications, which can adapt their behaviour in response to resource fluctuation, for example by trading precision for time (by returning an imprecise result to meet a deadline), or time for memory (by caching less to reduce memory consumption).

Runtime monitoring can be used to check whether a program meets a safety property specified in a propositional temporal logic. Tools like JPaX [[9](#_bookmark32)] compile a specification into a finite automaton which runs in parallel with the program, observing its behaviour. This kind of temporal specification can express resource protocols like authorise-before-use but is not expressive enough to capture protocols that involve counting potentially unbounded resources.

Schneider [[13](#_bookmark36)] advocates a similar use of (not necessarily finite) automata for enforcing security policies at runtime. [[15](#_bookmark38)] extends this by allowing an application to query the policy for compliance with a planned sequence of actions. Thus, the application can react gracefully to the policy’s decisions; our resource managers provide a similar policy query feature through the enable method.

# Conclusion

We have designed a Java library for tracking and monitoring the use of external re- sources on MIDP mobile phones (e. g. sending text messages). The library improves the flexibility of runtime monitoring in MIDP (which previously was in the hands of the user), providing a clear user interface and flexible policies while maintaining the security guarantee that any attempt to abuse resources will be trapped.

Our technical contribution is an API for fine-grained accounting of external resources, where fine-grained accounting is achieved by resource managers tracking not just a fixed set of resources but an input-dependent unbounded set (e. g. phone numbers from the user’s address book). The API is extensible, admitting to add new resource types and new policies by extending the class hierarchy. Moreover, we have outlined how a trusted library implementing the API can be deployed to MIDP phones as part of a potentially malicious application in such a way that the application cannot subvert the security guarantee (turning the application into a less malicious one). Finally, resource monitoring can be switched off by “erasing”

resource managers, which reduces the overhead without changing the observable behaviour of resource safe applications (and we are working on a type system for certifying resource safety [[2](#_bookmark25), chapter 3.3]).

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