

cloudRmpi Manual

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cloudRmpi is means for doing parallel processing in R, using MPI on a cloud-based network. It currently supports the use of Amazon's EC2 cloud computer service. *cloudRmpi* provides a mechanism to launch and manage a cloud-based network and to access an R session on the network's master MPI node (using the *rreval* package). *cloudRmpi* should work with any MPI based R package (it has been tested with *Rmpi*, *npRmpi*, and *snow*).

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1. Overview

'Cloud' computing services provide a relatively low cost way of doing parallel processing. The *cloudRmpi* package provides a means for doing parallel processing in R using these kinds of facilities. It currently supports the creation and use of networks running Open MPI on Amazon's cloud computer service, EC2. We hope to add support for other vendors' cloud computing services in the near future.

There are two main elements in the *cloudRmpi* package: an application for creating and managing EC2 networks (that support Open MPI and R), and functions for accessing an R session on the master node of the network.

The network manager is a java application, launched from within R with the `ppe.launchNetworkManager()` function (see [How to use *cloudRmpi*](#), below). ('ppe' stands for 'parallel processing with EC2'. The network manager has also been released in a non-R package, [ppe-ompi](#).)

A network launched with the *cloudRmpi* network manager contains one host that is designated the Open MPI master node. That master node runs an R session that is accessible remotely using functions in the *rreval* package. Using the access functions is covered in [How to use *cloudRmpi*](#), below.

Note that public cloud computing services like EC2 are commercial products. See the [Costs](#) section below for a discussion of the costs involved in using *cloudRmpi*.

2. Requirements/Prelims

Besides installing the *cloudRmpi* package in R, there are few other requirements.

1. Java (≥ 1.6)

The Java interpreter must be in your execution path. To test whether you have an accessible copy of Java, at a command line type

```
java -version
```

If Java is installed, you should get something like

```
java version "1.6.0_26"  
Java(TM) SE Runtime Environment (build 1.6.0_26-b03)  
Java HotSpot(TM) 64-Bit Server VM (build 20.1-b02, mixed mode)
```

(Why Java? See the *Architecture* section below.)

2. An [AWS](#) account.
3. Once you have an account
 1. Register for the EC2 service; you can do this via [AWS Account Management](#).
 2. Create and download an EC2 RSA keypair using the [AWS Management Console](#) (EC2 tab, NETWORK & SECURITY -> Key Pair). You will need the key pair name the first time you use *cloudRmpi*.
 3. Get the following strings from your Amazon account [Security Credentials](#) page.

Account number
Access Key ID
Secret Access Key

The 'Access Key ID' and 'Secret Access Key' are in the 'Access Credentials' section, in the 'Access Keys' tab. You will need these strings the first time you use *cloudRmpi*.

3. How to use cloudRmpi

3.1 Creating a network

3.1.1 Launch the ec2 network manager

In a local R session

```
library(cloudRmpi)
```

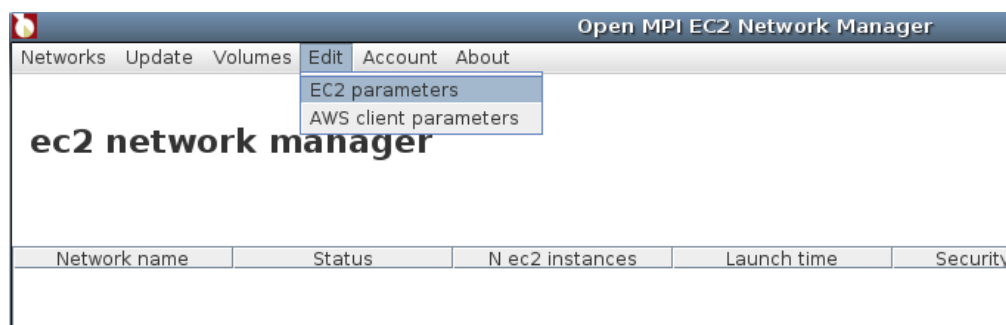
Launch the network manager:

```
ppe.launchNetworkManager()
```

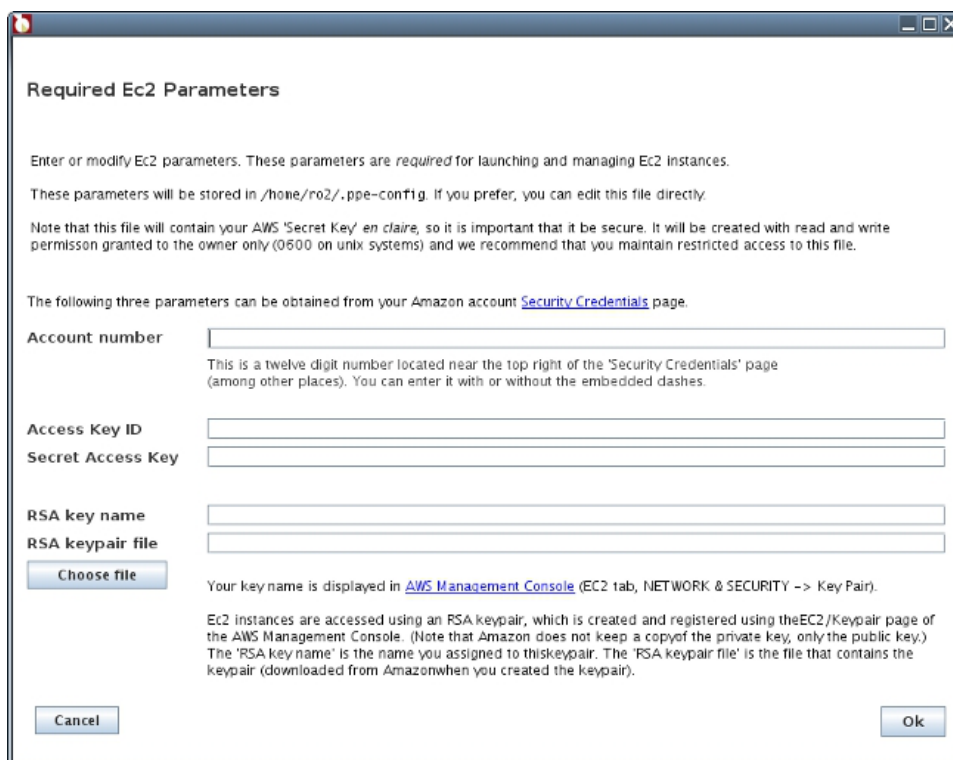
The first time time you launch the network manager

(a) Required parameters

You'll need to supply some values that are required to launch ec2 instances. From the top menu bar, use Edit -> EC2 parameters, ie.



This brings up the "Required Ec2 Parameters" entry window:



Required Ec2 Parameters

Enter or modify Ec2 parameters. These parameters are required for launching and managing Ec2 Instances.

These parameters will be stored in `/home/no2/.ppe-config`. If you prefer, you can edit this file directly.

Note that this file will contain your AWS 'Secret Key' *en clair*, so it is important that it be secure. It will be created with read and write permission granted to the owner only (0600 on unix systems) and we recommend that you maintain restricted access to this file.

The following three parameters can be obtained from your Amazon account [Security Credentials](#) page.

Account number

This is a twelve digit number located near the top right of the 'Security Credentials' page (among other places). You can enter it with or without the embedded dashes.

Access Key ID

Secret Access Key

RSA key name

RSA keypair file

Your key name is displayed in [AWS Management Console](#) (EC2 tab, NETWORK & SECURITY -> Key Pair).

Ec2 instances are accessed using an RSA keypair, which is created and registered using the EC2/Keypair page of the AWS Management Console. (Note that Amazon does not keep a copy of the private key, only the public key.) The 'RSA key name' is the name you assigned to this keypair. The 'RSA keypair file' is the file that contains the keypair (downloaded from Amazon when you created the keypair).

These values will be stored in a configuration file named `.ppe-config` that will be created in your home directory. You can change these values using the Edit -> EC2 Parameters menu item in the main network manager window or by editing the file directly.

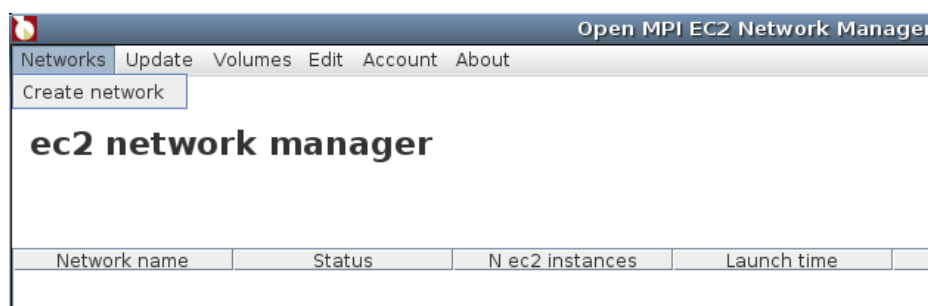
(b) Optional billing authorization

We charge \$0.03 per hour per instance for use of our most recent machine images (AMIs). This is billed through Amazon but requires separate authorization. For details and to authorize billing, select Account -> Authorize instance billing from top menubar of the main network manager window.

(c) Optional AWS client parameters

If you access the internet through a proxy server, you *may* need to set some Amazon client configuration parameters before you can launch ec2 instances. You can set any of these parameters via Edit -> AWS client parameters in top menu bar of the main network manager window. See [Amazon's documentation](#) for details on these parameters. If in doubt, we suggest that you first try to create a network without setting any of these parameters.

3.1.2 Specify and create a network



Open MPI EC2 Network Manager

Networks Update Volumes Edit Account About

Create network

ec2 network manager

Network name	Status	N ec2 instances	Launch time

Select an [instance type](#)

For most purposes (other than testing), you'll probably want to choose `cc1.4xlarge` or `cc2.8xlarge` because they can be run in a [cluster placement group](#). See [Choosing an Instance Type](#) for more information. If you choose one of these instance types, the application manager will launch your instances in a cluster placement group.

Specify ec2 network

Instance types

	Cores	GB ram	Cluster	Price
<input checked="" type="radio"/> cc1.4xlarge	8	23.0	yes	\$1.30
<input type="radio"/> cc2.8xlarge	16	60.5	yes	\$2.40
<input type="radio"/> cg1.4xlarge	8	22.0	yes	\$2.10
<input type="radio"/> c1.xlarge	8	7.0	no	\$0.66
<input type="radio"/> m2.xlarge	2	17.1	no	\$0.45
<input type="radio"/> m2.2xlarge	4	34.2	no	\$0.90
<input type="radio"/> m2.4xlarge	8	68.4	no	\$1.80
<input type="radio"/> m1.large	2	7.5	no	\$0.32
<input type="radio"/> m1.xlarge	4	15.0	no	\$0.64
<input type="radio"/> t1.micro	1	0.6	no	\$0.02

AMIs

	R	rreval	Price
<input type="radio"/> ami-5a04df33	2.15.0	1.1	\$0.03
<input type="radio"/> ami-dc30ebb5	2.15.0	1.1	\$0.03
<input type="radio"/> ami-5608d73f	2.14.2	1.0	\$0.00
<input type="radio"/> ami-58bb6431	2.14.2	1.0	\$0.00
<input type="radio"/> Other:	<input type="text"/>		

Choose a [machine image \(AMI\)](#)

AMIs that are not compatible with the selected instance type are disabled.

Specify the [availability zone](#).

If you've chosen an instance type that supports clusters, select 'Use any zone'; your instances will be launched in cluster group and a cluster group always runs in a single zone. Otherwise, specifying a zone insures that your instances are not spread across multiple zones (which may or may not be worth something re communications). However, if you are using an [Amazon Elastic Block Store \(EBS\)](#) for persistent storage, you must launch your instances in the availability zone where the EBS volume resides. An EBS volume can only be attached to an instance in its availability zone. (An AMI resides in a [region](#) and can be launched in any availability zone within that region.)

Availability zone

- ☒ Use any zone.
- ☐ us-east-1a
- ☐ us-east-1b
- ☐ us-east-1c
- ☐ us-east-1d
- ☐ us-east-1e

Security group

- ☒ Default
- ☐ Other:

Keypair

- ☒ bw_keypair0
- ☐ Other:

Network name:

Slots per host:

☐ Use spot instances, max price:

Number of instances:

Specify the [security group](#)

If 'Default' is selected, *cloudRmpi* will create an appropriate one-time security group. See [Security](#) for details.

Specify the [keypair](#)

Normally, select the keypair that you specified in the "RSA keypair name" field of the "Required Ec2 Parameters" entry form.

Spot instances

If you want to use [spot instances](#), specify a spot price. (Make sure that you understand the limitations of spot instances.) Note that as of 2011, all instance types are available as spots.

Network name

cloudRmpi will automatically generate a unique network name (you can change it).

Slots per host

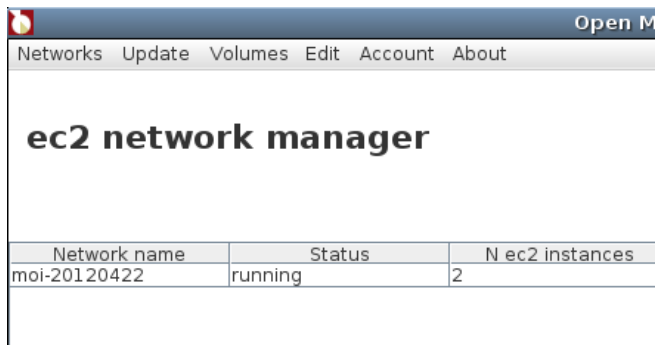
The number of slots per host is automatically generated based on the instance type selected (you can change it). This value is used to create the *ompi* hostfile.

Specify the number of instances

When you hit 'Continue' you'll have a chance to check the network's specification before it's launched.

3.2 Using the network

The network is ready for use when its status is "running":



Note that Amazon tools (such as the [Amazon Management Console](#)) will show your instances with status 'running' before the EC2 network manager does. AWS's monitoring lists instances as 'running' as soon as they are launched, even before the operating system has finished booting. After launching a network, network manager waits for the operating system to boot and then performs some configuration. It does not show the network's status as 'running' until all instances are booted and configured.

Occasionally an instance will not launch successfully. You may want to use the Amazon Management Console to monitor this - watch for instances that get 'stuck' with "Status Checks" equal to "initializing ...". If an instance does not respond, after ten minutes you'll be given the option of terminating it and proceeding.

Connect to an R session running on the master node of the network:

```
ppe.startClient()
```

('ppe' stands for 'parallel processing on EC2').

(On a few occasions, `ppe.startClient()` has returned `java.net.SocketException: Connection reset ...`, which indicates a transmission error. If this happens, just try `ppe.startClient()` again.)

Once you're connected, you can evaluate expressions. E.g.

```
re(1+1)
```

will return the value 2. An expression like

```
re(a <- seq(1,100)^2)
```

will create an object named 'a' in the remote R session *and* return the value of the expression.

To retrieve an expression from the remote session

```
re(a)
```

or to assign it locally

```
aa <- re(a)
```

To upload an object

```
z <- sin(pi)
upo(z)
```

(To move large objects, you may want to use the scp transfer functions, `scpUpload()` and `scpDownload()`; see the package documentation for details.)

You can evaluate any expression in the remote session, including things like

```
re(library(npRmpi))
re(ls())
```

It is perfectly acceptable to upload functions, e.g.

```
fn <- function(x) { quantile(x, seq(0,1,0.1)) }
upo(fn)
```

Errors will be handled gracefully, e.g.

```
re(lss())
```

yields the error message

```
<simpleError in eval(expr, envir, enclos): could not find function
"lss">
```

Note that all expression evaluations and assignments in the remote R session are performed in `.GlobalEnv` (the top level of the scope hierarchy). Of course you can explicitly specify other environments (e.g. `re(assign(x="a", value=1234, envir=some.other.envir))`).

When your done using the network, close the connection with

```
ppe.closeClient()
```

and, more importantly, terminate the network using the application manager

Network name	Status	N ec2 instances
ro2-20120303	running	4
<div>Reboot instances</div> <div>Terminate instances</div>		

Remember that Amazon will be charging you for your EC2 instances until you terminate them. You can also terminate your network with `ppe.terminateNetwork()` or with the [Amazon Management Console](#).

3.3 Accessing the network with ssh

Alternatively, you can access your ec2 network via ssh. EC2 instances are accessible using you RSA key (but not via password). E.g.

```
ssh -i your_keypair_file.pem ec2-user@ec2-174-129-172-112.compute-1.amazonaws.com
```

where `ec2-174-129-172-112.compute-1.amazonaws.com` is the URL of the network's master node. (You can get the master node's URL from the network manager or with the R function `ppe.getMasterNodeURL(...)`. See the `cloudRmpi` package documentation for details.)

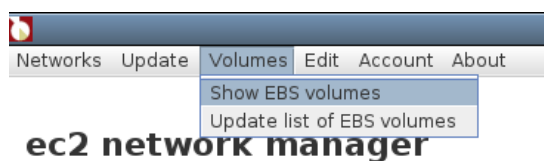
Once you've ssh'd into the master node you can start a standard R session from the command line.

3.4 Using EBS for persistent storage

When a EC2 instance is terminated, anything that was written the to disk is lost. However, you can attach persistent disk space to an EC2 instance using what AWS terms an [Amazon Elastic Block Store \(EBS\)](#). The operating system sees an EBS as device (like a hard drive). *ppe-ompi* provides support for using EBS.

You can create an EBS volume with the [AWS Management Console](#) (EC2 tab -> Navigation sidebar Elastic Block Store: Volumes). You do not need to have any instances running to create volumes.

To use an EBS volume with a specific EC2 instance, you must 'attach' it to the volume and then mount it (like any other Unix volume). You can get a list of your EBS volumes and their statuses from the ec2 network manager i.e.



You can attach the volume using an instance popup menu e.g.

moi-20120422

Public DNS	Status	Node type	Launch time	Instance type
ec2-184-73-6-230.compute-1.amazonaws.com		master	2012 04 22 01 19 14	t1.micro
ec2-23-22-40-208.compute-1.amazonaws.com		slave	2012 04 22 01 19 14	t1.micro

Public DNS

Launch shell for this instance

Attach EBS volume

Detach EBS volume

vol-7853f717 available us-east-1b nbl-data-1

(You can also list and attach volumes using the AWS Management Console.)

To make an EBS volume accessible, you'll need to use Linux commands. You can ssh to your instance e.g.

```
ssh -i your_keypair_file.pem ec2-user@ec2-174-129-172-112.compute-1.amazonaws.com
```

or you can use an ssh shell that is built into *ppe-mpi*.

A newly created volume does not have a file system. After attaching it to an instance, you'll need to use the standard Linux utility `mkfs`, e.g.

```
sudo mkfs -t ext3 /dev/sdf
```

And of course you need to mount the device

```
sudo mount /dev/sdf /home/ec2-user/your-mount-point
```

See [Amazon's documentation](#) for details.

Note that an EBS volume resides in what Amazon terms an [availability zone](#), and can only be attached to an EC2 instance running in that zone. So if you intend to attach an EBS volume to an instance in a *ppe-mpi* network, you must launch the network in the EBS volume's zone (see [Specify and create a network](#), above). An AMI resides in a 'region', which contains multiple availability zones, and all *ppe-mpi* AMIs reside in the us-east-1 region. So to use an EBS volume with *ppe-mpi*, it must be created in one of the us-east-1 zones.

4. Choosing an instance type

Amazon's EC2 service supplies computers with various processor types and memory configurations, which it terms [instances](#). While you can use *cloudRmpi* with any instance type, there is a substantial advantage to using instance types `cc1.4xlarge` or `cc2.8xlarge` for parallel processing. Each of these instance types can be launched in a [cluster placement group](#), which guarantees a specified bandwidth between instances. Other instance types cannot (except for the `gpu` cluster instance type).

When *cloudRmpi* launches a network of instances that can run in a cluster, those instances are always put into a placement group. This provides the fastest network communications available from AWS. According to Amazon, cluster placement groups are intended for `hpc`.

5. Costs

There are no sunk costs when using EC2 (or in creating or maintaining an AWS account); charges are strictly based on usage. The main costs are the [hourly instance charges](#), which vary with the instance type. AWS also charges for data transfers in and out of EC2 instances (see the "Data Transfer" section of [Amazon EC2 Pricing](#)), although transfer charges are usually small compared to instance charges. There is no charge for data transfers between instances in the same 'region'. In addition, we now charge \$0.03 for use of our most recent machine images (AMIs).

6. Security

Since EC2 is a web base service, security is inevitably a concern. Following is a brief description of security associated with *cloudRmpi*.

The *cloudRmpi* network manager launches and manages instances using the [AWS SDK for Java](#), which generates commands in the underlying EC2 api, composed of REST and SOAP commands. By default, all commands are transmitted using SSL. Commands must include the user's AWS 'Access Key ID' and 'Secret Access Key'. *cloudRmpi* reads these strings from the configuration file `.ppe-conf` in the user's home directory. This file is *en claire*, so it is

important that it *not* be publicly accessible. On Unix systems, this file's permission bits should be set to 0600 (e.g. `chmod 0600 .ppe-config`).

EC2 instances are launched within what AWS terms a [security group](#), which is equivalent to a firewall. By default, *cloudRmpi* creates a one-time security group and launches instances into that group. The default security group has the following configuration:

From port	To port	Protocol	Accessible from
22	22	tcp	All ip addresses
1	21	tcp	Group members only
23	65535	tcp	Group members only
1	65535	udp	Group members only
16020	16020	tcp	All ip addresses

In other words, instances within the network have unrestricted access to each other (which is necessary for Open MPI), but are only accessible from the rest of the world via ssh (port 22). 16020 is used to send messages to a monitor program running on an EC2 instance.

Each EC2 instance is associated with an RSA key. The public portion of this key must be registered with AWS before instances can be launched; its name is specified as part of instance requests. After instances are launched, *cloudRmpi* uses the private key to access the instances (via ssh), to perform some setup. *cloudRmpi* gets the key name and the path to the keypair file from `.ppe-conf`. Obviously it is important to keep the configuration file and the key pair file secure. The private key exists only on the user's local system. Amazon provides a utility for creating an RSA keypair and recording the public key, but it does *not* keep a copy of the private key.

cloudRmpi instances are configured to support ssh login using the RSA key only. There are no passwords. (This is standard practice with EC2 instances.) Each instance has a user named `ec2-user`. The only way to access a node in a *cloudRmpi* network is via ssh, e.g.

```
ssh -i your-rsa-keypair-file.pem ec2-user@ec2-123-456-789-123.compute-1.amazonaws.com
```

and similarly with scp.

Communications between your local R session and the R session on the master node of the EC2 network go through a pair of java apps, one on the local system and the other on the network master node (see [Architecture](#) for details). These java apps perform socket level communication via ssh port forwarding. So when you use functions like `re()` or `up()` to perform operations in the remote R session, communications is via ssh.

7. Dependencies

cloudRmpi depends on two R packages, *digest* and *rreval*. It also uses the following third-party packages:

- [AWS SDK for Java](#) Note that the AWS sdk distribution itself contains third party software (see `inst/third-party/aws-java-sdk-1.3.3/third-party` in the *cloudRmpi* distribution for details).
- [Ganymed SSH-2 for Java](#)
- [GNU Trove: High performance collections for Java](#).
- [Apache Http Components Core](#)
- [Amazon FPS Java Library](#)

See the `third-party` directory in the *cloudRmpiJars* package for these packages' licenses.

We have previously released the network management application in the *ppe-mpi* project (which is released under GPL 3.0).

8. Machine images

An EC2 network consists of one or more hosts (termed [instances](#) by Amazon) running a virtualized operating system termed an [Amazon Machine Images](#) (AMI). In addition to the operating system, an AMI can contain application software and can be configured to launch applications when booted.

[Amazon Machine Images](#) (AMIs) with Open MPI and R installed are listed [here](#)

To use a [cluster placement group](#), you must use an image with hmv virtualization. Otherwise you can use a paravirtual image (see [Choosing an instance type](#)).

These images are configured to start an R session and launch the server function `rreServer()` when booted. I.e. they are ready to be to accept a connection from `ppe.startClient()` as soon as the boot process is complete.

9. Architecture

cloudRmpi has two main components: the network manager and a client-server mechanism for evaluating expressions in an R session running on the network's master MPI node.

Network Manager

The network manager is java app that is launched on the local system by the function `ppe.launchNetworkManager()`. Communications between the R session and the network manager are via a socket. The network manager is always launched on the same system as the local R client. Communications between the R session and the network manager are *en clair*.

The network manager creates a network of EC2 instances using the [AWS SDK for Java](#) which sends command to AWS via using SSL. As part of the request for instances that it submits to AWS, it creates a one time security group (see [Security](#) for details).

After submitting a request for instances, the network manager continually monitors the status of the request and the status of the instances once they are launched. Once all instances are available, it performs the following configuration related operations:

- Designates one instance as the MPI master node, and the rest as slaves.
- Creates a one time RSA keypair and installs it on the master. The public portion is installed on the slaves. NOTE that this keypair is used for communications between nodes only and is completely distinct from the user's keypair. The user's keypair is used for launching instances and for access to the network. The private key of your keypair resides on your local system and is never transferred anywhere.
- Creates an `ompi` host file, `~ec2-user/ompi-hostfile` on the master.
- Disables hyperthreading on all instances.

Remote evaluation, client-server communications

cloudRmpi uses the *rreval* package to access an R session on the master MPI node of the EC2 network. *cloudRmpi* has some functions (such as `ppe.startClient()`) that are essentially wrappers for *rreval* functions; they make using *rreval* on with an EC2 network more convenient, but the underlying code is the same.

rreval is a means for using R on a remote system from within a local R session. Any R expression can be evaluated on the remote server. All non-graphical results are returned to the local R session: this includes the results of remote evaluations and (nearly) all textual output, including errors and warnings.

Expressions are evaluated by an R session on the MPI master node that is running the *rreval* server. When a local R session connects to a server, the local client has exclusive use of the remote R session until it disconnects; i.e. an R server handles only one client at a time.

Communication between the client and server is performed by a pair of java apps, `rreval.RReClientApp` and `rreval.RReServerApp`. The local R session sends a command to the `rreval.RReClientApp`. After performing error checks, the command is sent to `rreval.RReServerApp` which runs on the remote system. It in turn passes the command to the *rreval* server. The results of evaluation are returned by this path in reverse.

The two java apps communicate via ssh port forwarding, so communication between them should be secure. Note that communications between an R session and a java app are *en clair*. These are local socket communications so security should not an issue.

10. Handling problems

Handling errors in a parallel processing environment can be messy, and R parallel processing packages are no exception. For example, if you use the *npRmpi* function

```
mpi.bcast.cmd(bw.hit <- npcdensbw(y ~  
x, data=obs), caller.execute=TRUE)
```

without first broadcasting `obs` (i.e. `mpi.bcast.Robj2slave(obs)`), the call to `npcdensbw` will hang and there's no way to interrupt it.

Although it sounds crude, the best way we've found to handle this kind of situation is to simply

reboot all the instances in the network. The network manager has a command to reboot an entire network:

Network name	Status	N ec2 instances
ro2-20120303	running	4
<div>Reboot instances</div> <div>Terminate instances</div>		

Of course you will loose everything in your remote R session. We usually make liberal use of `re(save.image())`. When you reboot a EC2 instance, anything you've written to disk is preserved (which is *not* the case when you terminate an instance). It's not a terribly elegant solution, but it's the best we've come up with so far.