ns-3 Direct Code Execution (DCE) Manual

Release 1.10-23-g129c14c

Direct Code Execution project

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This is the manual of Direct Code Execution (DCE).

- **Doxygen**: Documentation of the public APIs of the DCE
- **Manual** *(this document)* for the latest release and development tree

This document is written in reStructuredText for Sphinx and is maintained in the `doc/` directory of ns-3-dec’s source code.
CHAPTER ONE

INTRODUCTION

1.1 Overview

Direct Code Execution (DCE) is a module for ns-3 that provides facilities to execute, within ns-3, existing implementations of userspace and kernelspace network protocols or applications without source code changes. For example instead of using the pseudo application provided by ns-3 V4PingHelper you can use the true ping.

If you wish to cite DCE in your academic work, please reference this paper.

1.2 Maintainers

DCE is maintained by Hajime Tazaki and Matthieu Coudron.

1.3 Manual Structure

This document consists of the following parts:

0. Quick Start: The document describes a quick instruction of DCE.
1. User’s Guide: The document is for people who will use DCE to experiment.

1.4 DCE Outlook

• To run an application using DCE, it is usually not necessary to change its sources. However you will need to recompile them.
• The simulation is executed wholly within a single process which greatly facilitates the debugging.
• DCE is very memory-efficient, thanks to the way it loads the executables similarly to shared libraries.

1.5 Supported Features

• Simulation with POSIX socket application (no manual modifications)
• C/C++ applications
• Simulation with Linux kernel implemented network protocol
• IPv4/IPv6
• TCP/UDP/DCCP
• running with POSIX socket applications and ns-3 socket applications
• configuration via sysctl-like interface
• multiple nodes debugging with single gdb interface
• memory analysis by single valgrind execution with multiple nodes
• Variance of network stacks
• ns-3 native stack (IPv4/IPv6, partially)
• Network simulation cradle network stack (IPv4 TCP only)
• Linux network stack (IPv4/IPv6/others)
• Per-node configuration(stdin input
• Per-node syslog/stdout/stderr files output

1.6 Tested Applications

• CCNx
• Quagga
• iperf
• ping/ping6
• ip (iproute2 package)
• Mobit IPv6 daemon (umip)
• Linux kernel (from 2.6.36 to 3.7 versions)
• http server (thttpd)
• torrent (libtorrent from rasterbar + opentracker)

1.7 Tested Environment

Currently, DCE only supports Linux-based operating systems. DCE has been tested on the following distributions:

• Ubuntu 16.04 and equivalents (gcc-5.4, libc-2.23)

but you can try on others (e.g., CentOS, RHEL). However, unfortunately only a narrow range of older Linux systems work with DCE (gcc-5-based systems such as Ubuntu 16.04).

If you find that you can run on another distribution, please let the Maintainers know. Also, if you would like to work on getting DCE to work on newer systems, please let the Maintainers know.
CHAPTER TWO

QUICK START

2.1 Introduction

The DCE ns-3 module provides facilities to execute within ns-3 existing implementations of userspace and kernelspace network protocols.

As of today, the Quagga routing protocol implementation, the CCNx CCN implementation, and recent versions of the Linux kernel network stack are known to run within DCE, hence allowing network protocol experimenters and researchers to use the unmodified implementation of their protocols for real-world deployments and simulations.

2.2 Build DCE

DCE offers two major modes of operation:

1. The basic mode, where DCE use the ns-3 TCP stacks,
2. The advanced mode, where DCE uses a Linux network stack instead.

2.2.1 Building DCE basic mode

First you need to download Bake using Git and set some environment variables:

```bash
git clone https://gitlab.com/nsnam/bake.git
cd bake
export PATH=\$PATH:pwd\'/build/bin:pwd\'/build/bin_dce
export PYTHONPATH=\$PYTHONPATH:pwd\'/build/lib
export LD_LIBRARY_PATH=\$LD_LIBRARY_PATH:pwd\'/build/lib
```

then you can install it using bake:

```bash
bake.py configure -e dce-ns3-\$version
bake.py check
bake.py show
```

The check and show commands show you missing packages needed by the configured module. Please use your package manager to install missing ones, and then proceed with:

```bash
bake.py download
bake.py build
```
Note that dce-ns3-$version is the DCE module with a version number. If you would like to use the development version of DCE module, you can specify dce-ns3-dev as a module name for bake. As of March 2020, this (dev version) is recommended.

The output should look something like this:

```
Installing selected module and dependencies.
Please, be patient, this may take a while!
>> Downloading ccnx
>> Download ccnx - OK
>> Downloading iperf
>> Download iperf - OK
>> Downloading ns-3-dev-dce
>> Download ns-3-dev-dce - OK
>> Downloading dce-ns3
>> Download dce-ns3 - OK
>> Building ccnx
>> Built ccnx - OK
>> Building iperf
>> Built iperf - OK
>> Building ns-3-dev-dce
>> Built ns-3-dev-dce - OK
>> Building dce-ns3
>> Built dce-ns3 - OK
```

### 2.2.2 Building DCE advanced mode (with Linux kernel)

If you would like to try Linux network stack instead of ns-3 network stack, you can try the advanced mode. The difference to build the advanced mode is the different module name dce-linux instead of dce-ns3 (basic mode).

Listing 2.1: Installation of DCE via bake

```
bake.py configure -e dce-linux-$version
bake.py check
bake.py show
bake.py download
bake.py build
```

Note that dce-linux-$version is the DCE module with a version number. If you would like to use the development version of DCE module, you can specify dce-linux-dev as a module name for bake.

### 2.2.3 Building DCE using WAF

While Bake is the best option, another one is the configuration and build using WAF. WAF is a Python-based framework for configuring, compiling and installing applications. The configuration scripts are coded in Python files named `wscript`, calling the WAF framework, and called by the `waf` executable.

In this case you need to install the single packages one by one. You may want to start with ns-3:

- GIT_NS3= git@gitlab.com:nsnam/ns-3-dev.git
- LAST_VERSION= ns-3.30
Listing 2.2: ns-3 installation

```bash
export HOME=`pwd`
mkdir dce
cd dce
# Download pybindgen (optional)
git clone https://github.com/gjcarneiro/pybindgen.git
cd pybindgen
python3 setup.py install
# Download ns-3
# git instructions
git clone GIT_NS3
git checkout LAST_VERSION
# Configure
./waf configure --enable-examples -d optimized --prefix=$HOME/dce/install
# Build and install in the directory specified by
# --prefix parameter
./waf build
./waf install
```

More detailed information on installation requirements can be found on the ns-3 wiki.

Then you can download and install net-next-nuse and DCE (*net-next-nuse includes the linux stack module):

- GIT_DCE= git@github.com:direct-code-execution/ns-3-dce

Listing 2.3: Kernel and DCE installation

```bash
# Clone net-next-nuse
git clone https://github.com/libos-nuse/net-next-nuse.git
cd net-next-nuse
# Select a kernel version
git checkout libos-v4.4
# Configure and build
make defconfig OPT=yes ARCH=sim
make library OPT=yes ARCH=sim
cd ..
# Download, configure, build and install DCE
git clone GIT_DCE
./waf configure --with-ns3=$HOME/dce/build --enable-opt \
 --enable-kernel-stack=$HOME/dce/net-next-nuse/arch \
 --prefix=$HOME/dce/install
./waf build
./waf install
```

### 2.3 Examples

If you succeeded to build DCE, you can try an example script which is already included in DCE package.
2.3.1 Example: Simple UDP socket application

This example execute the binaries named udp-client and udp-server under ns-3 using DCE. These 2 binaries are written using POSIX socket API in order to send and receive UDP packets.

If you would like to see what is going on this script, please refer to the user’s guide.

Listing 2.4: Listing of the files generated by the dce-udp-simple example

```bash
$ cd source/ns-3-dce
$ ./waf --run dce-udp-simple
$ ls
elf-cache  files-0  exitprocs
$ ls -lR files-0
files-0:
total 4
drwxr-x--- 3 furbani planete 4096 Sep 2 17:02 var

files-0/var:
total 4
drwxr-x--- 4 furbani planete 4096 Sep 2 17:02 log

files-0/var/log:
total 8
drwxr-x--- 2 furbani planete 4096 Sep 2 17:02 53512
drwxr-x--- 2 furbani planete 4096 Sep 2 17:02 53513

files-0/var/log/53512:
total 12
-rw------- 1 furbani planete 12 Sep 2 17:02 cmdline
-rw------- 1 furbani planete 185 Sep 2 17:02 status
-rw------- 1 furbani planete 0 Sep 2 17:02 stderr
-rw------- 1 furbani planete 21 Sep 2 17:02 stdout

files-0/var/log/53513:
total 12
-rw------- 1 furbani planete 22 Sep 2 17:02 cmdline
-rw------- 1 furbani planete 185 Sep 2 17:02 status
-rw------- 1 furbani planete 0 Sep 2 17:02 stderr
-rw------- 1 furbani planete 22 Sep 2 17:02 stdout
```

This simulation produces two directories, the content of elf-cache is not important now for us, but files-0 is. files-0 contains first node’s file system, it also contains the output files of the dce applications launched on this node. In the /var/log directory there are some directories named with the virtual pid of corresponding DCE applications. Under these directories there is always 4 files:

1. cmdline: which contains the command line of the corresponding DCE application, in order to help you to retrieve what is it,
2. stdout: contains the stdout produced by the execution of the corresponding application,
3. stderr: contains the stderr produced by the execution of the corresponding application.
4. status: contains a status of the corresponding process with its start time. This file also contains the end time and exit code if applicable.

Before launching a simulation, you may also create files-xx directories and provide files required by the applications to be executed correctly.
2.3.2 Example: iperf

This example shows the usage of iperf with DCE. You are able to generate traffic by well-known traffic generator *iperf* in your simulation. For more detail of the scenario description, please refer to the *user’s guide*.

Once you successfully installed DCE with bake, you can execute the example using iperf.

```bash
cd source/ns-3-dce
./waf --run dce-iperf
```

As we saw in the previous example the experience creates directories containing the outputs of different executables, take a look at the server (node 1) output:

```
$ cat files-1/var/log/*/stdout
------------------------------------------------------------
Server listening on TCP port 5001
TCP window size: 124 KByte (default)
------------------------------------------------------------
[ 4] local 10.1.1.2 port 5001 connected with 10.1.1.1 port 49153
[ID] Interval Transfer Bandwidth
[ 4] 0.0-11.2 sec 5.75 MBytes 4.30 Mbits/sec
```

the client (node-0) output below:

```
Listing 2.5: iperf output

$ cat files-0/var/log/*/stdout
------------------------------------------------------------
Client connecting to 10.1.1.2, TCP port 5001
TCP window size: 124 KByte (default)
------------------------------------------------------------
[ 3] local 10.1.1.1 port 49153 connected with 10.1.1.2 port 5001
[ID] Interval Transfer Bandwidth
[ 3] 0.0- 1.0 sec 640 KBytes 5.24 Mbits/sec
[ 3] 1.0- 2.0 sec 512 KBytes 4.19 Mbits/sec
[ 3] 2.0- 3.0 sec 640 KBytes 5.24 Mbits/sec
[ 3] 3.0- 4.0 sec 512 KBytes 4.19 Mbits/sec
[ 3] 4.0- 5.0 sec 512 KBytes 4.19 Mbits/sec
[ 3] 5.0- 6.0 sec 640 KBytes 5.24 Mbits/sec
[ 3] 6.0- 7.0 sec 512 KBytes 4.19 Mbits/sec
[ 3] 7.0- 8.0 sec 640 KBytes 5.24 Mbits/sec
[ 3] 9.0-10.0 sec 640 KBytes 5.24 Mbits/sec
[ 3] 0.0-10.2 sec 5.75 MBytes 4.72 Mbits/sec
```

if you have already built the advanced mode, you can use Linux network stack over iperf.

```bash
cd source/ns-3-dce
./waf --run "dce-iperf --stack=linux"
```

the command line option `--stack=linux` makes the simulation use the Linux kernel stack instead of *ns-3* network stack.

```
$ cat files-1/var/log/*/stdout
------------------------------------------------------------
Server listening on TCP port 5001
TCP window size: 85.3 KByte (default)
------------------------------------------------------------
[ 4] local 10.1.1.2 port 5001 connected with 10.1.1.1 port 60120
```
$ cat files-0/var/log/*/stdout

Client connecting to 10.1.1.2, TCP port 5001
TCP window size: 16.0 KByte (default)

Interestingly, the two results between two network stacks are slightly different, though the difference is out of scope of this document.
This document is for the people who want to use your application in \textit{ns-3} using DCE. Direct Code Execution (DCE) allows us to use POSIX socket-based applications as well as Linux kernel network stack.

### 3.1 Setup Guide

In order to install DCE you must follow the tutorial \textit{Build DCE}.

**Installation result**

The result of the installation process is the creation of libraries from source of DCE and that of \textit{ns-3} and also some tools and sources of an optional Linux kernel if you have also chosen to use the stack of a Linux kernel. Below you will find the main directories:

```
|--- bakefile.xml    Bake internal configuration file (generated by bake.py configure command).
|--- bakeSetEnv.sh   Bake generated file used to configure environmental variable.
|--- build           Target directory of \textit{|ns3| Core and DCE compilation.}
    |--- bin
    |--- bin_dce
    |--- etc
    |--- include
    |--- lib
    |--- sbin
    |--- share
    |--- usr
    |--- var
+--- source         Source directory during 'bake.py download'. Listed files below depend on the configuration of bake.
    |--- ccnx
    |--- ccnx-0.6.2.tar.gz
    |--- ns-3-dce
        |--- build
        |--- doc                  Documentation source
        |--- elf-cache
        |--- example              Example scenarios using DCE
        |--- files-0
        |--- files-1
        |--- files-2
        |--- files-3
        |--- files-5
```
3.2 Basic Use Cases

3.2.1 Using your userspace protocol implementation

As explained in How It Works, DCE needs to relocate the executable binary in memory, and these binary files need to be built with specific compile/link options.

In order to do this you should follow the following rules:

1. Compile your objects using this gcc flag: `-fPIC` for example: `gcc -fPIC -c foo.c`

1. (option) Some application needs to be compile with `-U_FORTIFY_SOURCE` so that the application doesn’t use alternative symbols including `__chk` (like `memcpy_chk`).

2. Link your executable using this gcc flag: `-pie` and `-rdynamic` for example: `gcc -o foo -pie -rdynamic foo.o`

3. Verify the produced executable using readelf utility in order to display the ELF file header and to verify that your exe is of type `DYN` indicating that DCE should be able to relocate and virtualize it under `ns-3` virtual world and network. For example: `readelf -h foo | grep Type: == Type: DYN (Shared object file)`

4. Check also that your executable runs as expected outside of `ns-3` and DCE.

Install the target executable

Copy the executable file produced in a specified directory in the variable environment `DCE_PATH` so that DCE can find it. `DCE_PATH` behaves like the variable PATH and can contain several directories such as `/home/USER/`
Write a ns-3 script

Now that you have compiled your executable you can use it within ns-3 script with the help of a set of DCE Helper Class:

<table>
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<tr>
<th>HELPER NAME</th>
<th>INCLUDE NAME</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>DceManager-Helper</td>
<td>ns3/dcemanager-helper.h</td>
<td>A DceManager is a DCE internal class which manage the execution of the executable you will declare to run within ns-3. The DceManagerHelper is the tool you will use within your script to parameter and install DceManager on the ns-3 nodes where you plan to run binaries.</td>
</tr>
<tr>
<td>DceApplication-Helper</td>
<td>ns3/dce-application-helper.h</td>
<td>You will use this helper in order to define which application you want to run within ns-3 by setting the name of the binary its optional arguments, its environment variables, and also optionally if it take its input from a file instead of stdin. This class can be derived if you need to do more preparation before running your application. Often applications need configuration file to work properly, for example if you look at the contents of the helper named CcnClientHelper you will see that his job is to create the key files needed for the operation of CCNx’s applications.</td>
</tr>
<tr>
<td>LinuxStack-Helper</td>
<td>ns3/linux-stack-helper.h</td>
<td>This helper is used to configure parameters of Linux kernel when we are using the advanced mode.</td>
</tr>
<tr>
<td>CcnClientHelper</td>
<td>ns3/ccn-client-helper.h</td>
<td>This helper is a subclass of DceApplicationHelper, its jobs is to create keys files used by ccnx executables in order to run them correctly within NS3.</td>
</tr>
<tr>
<td>Quagga-Helper</td>
<td>ns3/quagga-helper.h</td>
<td>This helper is a subclass of DceApplicationHelper. It will help you to setup Quagga applications.</td>
</tr>
</tbody>
</table>

Note that the table above indicates the name of includes, so you can look at the comments in them, but in reality for DCE use you need to include only the file ns3/dce-module.h.

The directory named myscripts is a good place to place your scripts. To create a new script you should create a new directory under myscripts, and put your sources and a configuration file for waf build system, this file should be named wscript. For starters, you may refer to the contents of the directory myscripts/ping.

For more detail, please refer DCE API (doxygen) document.

Compile the script

To compile simply execute the command waf. The result must be under the directory named build/bin/myscripts/foo/bar where foo is your directory and bar your executable according to the content of your wscript file.

Launch the script

Simply launch your script like any other program.
Results

The execution of the apps using DCE generates special files which reflect the execution thereof. On each node DCE creates a directory `/var/log`, this directory will contain subdirectory whose name is a number. This number is the pid of a process. Each of these directories contains the following files `cmdline`, `status`, `stdout`, `stderr`. The file `cmdline` recalls the name of the executable run followed arguments. The file `status` contains an account of the execution and dating of the start; optionally if the execution is completed there is the date of the stop and the return code. The files `stdout` and `stderr` correspond to the standard output of the process in question.

Example: DCE Simple UDP (dce-udp-simple)

The example uses two POSIX socket-based application in a simulation. Please take time to look at the source dce-udp-simple.cc:

```cpp
#include "ns3/network-module.h"
#include "ns3/core-module.h"
#include "ns3/internet-module.h"
#include "ns3/dce-module.h"

using namespace ns3;

int main (int argc, char *argv[]) {
    CommandLine cmd;
    cmd.Parse (argc, argv);
    NodeContainer nodes;
    nodes.Create (1);
    InternetStackHelper stack;
    stack.Install (nodes);
    DceManagerHelper dceManager;
    dceManager.Install (nodes);
    DceApplicationHelper dce;
    ApplicationContainer apps;
    dce.SetStackSize (1 << 20);
    dce.SetBinary ("udp-server");
    dce.ResetArguments ();
    apps = dce.Install (nodes.Get (0));
    apps.Start (Seconds (4.0));
    dce.SetBinary ("udp-client");
    dce.ResetArguments ();
    dce.AddArgument ("127.0.0.1");
    apps = dce.Install (nodes.Get (0));
    apps.Start (Seconds (4.5));
    Simulator::Stop (Seconds (1000100.0));
    Simulator::Run ();
```
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You can notice that we create a ns-3 Node with an Internet Stack (please refer to ns-3 doc. for more info), and we can also see 2 new Helpers:

1. DceManagerHelper which is used to Manage DCE loading system in each node where DCE will be used.
2. DceApplicationHelper which is used to describe real application to be launched by DCE within ns-3 simulation environment.

Example: DCE with iperf(dce-iperf)

The example uses iperf traffic generator in a simulation. The scenario is here:

```cpp
#include "ns3/network-module.h"
#include "ns3/core-module.h"
#include "ns3/internet-module.h"
#include "ns3/dce-module.h"
#include "ns3/point-to-point-module.h"
#include "ns3/applications-module.h"
#include "ns3/netanim-module.h"
#include "constant-position-mobility-model.h"
#include "ccnx/misc-tools.h"

using namespace ns3;
NS_LOG_COMPONENT_DEFINE ("DceIperf");

// node 0 node 1
// +----------------+ +----------------+
// | | | |
// +----------------+ +----------------+
// | 10.1.1.1 | | 10.1.1.2 |
// +----------------+ +----------------+
// | point-to-point | | point-to-point |
// +----------------+ +----------------+
// 5 Mbps, 2 ms

// Note : Tested with iperf 2.0.5, you need to modify iperf source in order to allow DCE to have a chance to end an endless loop in iperf as follow:
// in source named Thread.c at line 412 in method named thread_rest
// you must add a sleep (1); to break the infinite loop....

int main (int argc, char *argv[]) {
    std::string stack = "ns3";
    bool useUdp = 0;
    std::string bandWidth = "1m";
    CommandLine cmd;
    cmd.AddValue ("stack", "Name of IP stack: ns3/linux/freebsd.", stack);

3.2. Basic Use Cases
cmd.AddValue ("udp", "Use UDP. Default false (0)", useUdp);
cmd.AddValue ("bw", "BandWidth. Default 1m.", bandWidth);
NodeContainer nodes;
nodes.Create (2);

PointToPointHelper pointToPoint;
pointToPoint.SetDeviceAttribute ("DataRate", StringValue ("5Mbps"));
pointToPoint.SetChannelAttribute ("Delay", StringValue ("1ms"));

NetDeviceContainer devices;
devices = pointToPoint.Install (nodes);

DceManagerHelper dceManager;
dceManager.SetTaskManagerAttribute ("FiberManagerType", StringValue ("UcontextFiberManager"));

if (stack == "ns3")
{
    InternetStackHelper stack;
    stack.Install (nodes);
dceManager.Install (nodes);
}
else if (stack == "linux")
{
    #ifdef KERNEL_STACK
    dceManager.SetNetworkStack ("ns3::LinuxSocketFdFactory", "Library", StringValue("liblinux.so"));
    dceManager.Install (nodes);
    LinuxStackHelper stack;
    stack.Install (nodes);
    #else
    NS_LOG_ERROR ("Linux kernel stack for DCE is not available. build with dce-linux module.");
    // silently exit
    return 0;
    #endif
}
else if (stack == "freebsd")
{
    #ifdef KERNEL_STACK
    dceManager.SetNetworkStack ("ns3::FreeBSDSocketFdFactory", "Library", StringValue("libfreebsd.so"));
    dceManager.Install (nodes);
    FreeBSDStackHelper stack;
    stack.Install (nodes);
    #else
    NS_LOG_ERROR ("FreeBSD kernel stack for DCE is not available. build with dce-freebsd module.");
    // silently exit
    return 0;
    #endif
}

Ipv4AddressHelper address;
address.SetBase ("10.1.1.0", "255.255.255.252");
Ipv4InterfaceContainer interfaces = address.Assign (devices);
// setup ip routes
Ipv4GlobalRoutingHelper::PopulateRoutingTables();
#ifdef KERNEL_STACK
if (stack == "linux")
  {
    LinuxStackHelper::PopulateRoutingTables();
  }
#endif

DceApplicationHelper dce;
ApplicationContainer apps;
std::ostringstream serverIp;
dce.SetStackSize (1 << 20);

// Launch iperf client on node 0
dce.SetBinary ("iperf");
dce.ResetArguments ();
dce.ResetEnvironment ();
dce.AddArgument ("-c");

// Extract server IP address
Ptr<Ipv4> ipv4Server = nodes.Get (1)->GetObject<Ipv4> ();
Ipv4Address serverAddress = ipv4Server->GetAddress (1, 0).GetLocal ();
serverAddress.Print (serverIp);
dce.AddArgument (serverIp.str());
dce.AddArgument ("-i");
dce.AddArgument ("1");
dce.AddArgument ("--time");
dce.AddArgument ("10");
if (useUdp)
  {
    dce.AddArgument ("-u");
    dce.AddArgument ("-b");
    dce.AddArgument (bandWidth);
  }
apps = dce.Install (nodes.Get (0));
apps.Start (Seconds (0.7));
apps.Stop (Seconds (20));

// Launch iperf server on node 1
dce.SetBinary ("iperf");
dce.ResetArguments ();
dce.ResetEnvironment ();
dce.AddArgument ("-c");
dce.AddArgument ("-P");
dce.AddArgument ("1");
if (useUdp)
  {
    dce.AddArgument ("-u");
  }
apps = dce.Install (nodes.Get (1));
pointToPoint.EnablePcapAll ("iperf-" + stack, false);
apps.Start (Seconds (0.6));
setPos (nodes.Get (0), 1, 10, 0);
setPos (nodes.Get (1), 50, 10, 0);
Simulator::Stop (Seconds (40.0));
Simulator::Run ();
Simulator::Destroy ();
return 0;
}

This scenario is simple there is 2 nodes linked by a point to point link, the node 0 launch iperf as a client via the command `iperf -c 10.1.1.2 -i 1 –time 10` and the node 1 launch iperf as a server via the command `iperf -s -P 1`. You can follow this to launch the experiment:

### 3.2.2 Using your in-kernel protocol implementation

There are a number of protocols implemented in kernel space, like many transport protocols (e.g., TCP, UDP, SCTP), Layer-3 forwarding plane (IPv4, v6 with related protocols ARP, Neighbor Discovery, etc). DCE can simulate these protocols with *ns-3* and a kernel compiled as a library. This is not possible with the linux vanilla kernel hence you need to use a slightly modified kernel (net-next-sim - deprecated - or libos which is the successor of net-next-sim).

This document describes how to retrieve, configure, compile and use this custom kernel in DCE. As an example, it shows how to enable an in-tree but optional protocol - Stream Control Transmission Protocol (SCTP) - and an out of tree protocol: Multipath TCP (MPTCP). Although other protocols may not adapt these patterns as-is, you will see what’s needed to implement for your purpose.

- 1. Configure a kernel (make menuconfig in Linux)
- 2. Build a DCE compatible linux kernel
  - 2.1 With net-next-sim (deprecated)
  - 2.2 Build an MPTCP kernel with net-next-sim
  - 2.3 With libos
- 3. Write user space application to use this protocol
- 4. Write ns-3 scenario to use above applications.
- 5. run it!

#### 1. Configure a kernel (make menuconfig in Linux)

In Linux kernel, there is a configuration system in Linux kernel to enable/disable features. This is typically done by `make menuconfig` command, and it writes a file (.config) at the kernel source directory. Build system (e.g., make bzImage) refers the file which source files are compiled.

In our DCE Linux kernel module (i.e. net-next-sim available at github.com), we have `arch/sim/defconfig` file to store the default configuration of kernel features. You may need to add proper configuration parameters (e.g., CONFIG_IP_SCTP) to build the protocol by default.
3.2. Basic Use Cases

Network options

Arrow keys navigate the menu. <Enter> selects submenus ---> (or empty submenus ----). Highlighted letters are hotkeys. Pressing <Y> includes, <N> excludes, <M> modularizes features. Press <Esc><Esc> to exit, <? for Help, </> for Search. Legend: [*] built-in [ ]

-<M> IP: AH transformation
-<M> IP: ESP transformation
-<M> IP: IPComp transformation
-<M> IP: IPsec transport mode
-<M> IP: IPsec tunnel mode
-<M> IP: IPsec BEEF mode
< > Large Receive Offload (ipv4/tcp)
< > INET: socket monitoring interface
< > UDP: socket monitoring interface
[*] TCP: advanced congestion control --->
[ ] TCP: MDS Signature Option support (RFC2385)
[ ] The IPv6 protocol --->
[ ] Security Marking
[ ] Timestamping in PHY devices
[ ] Network packet filtering framework (Netfilter) ----
<*> The DCCP Protocol --->
<*> The SCIP Protocol ---->
< > The RDS Protocol
< > The TIPC Protocol ----
<*> Asynchronous Transfer Mode (ATM)

Select > Exit > Help > Save > Load >
For the Linux SCTP implementation, we need at least the following configuration parameters.

- CONFIG_IP_SCTP=y
- CONFIG_SCTP_DEFAULT_COOKIE_HMAC_NONE=y
- CONFIG_CRYPTO_CRC32C=y
- CONFIG_CRC32=y

These can be added to the file (arch/sim/defconfig) or added manually to .config when needed.

**Note**

These configuration options SHOULD be minimized at the beginning since adding new option may require new functions which DCE doesn’t support at the time and need to implement glue code.

### 2. Build a DCE compatible linux kernel

DCE can simulate these protocols with ns-3 and a kernel compiled as a library named `liblinux.so`. This is not possible with the linux vanilla kernel hence you need to use a slightly modified kernel (net-next-sim - deprecated - or libos which is the successor of net-next-sim). The following section presents the two methods, net-next-sim being slightly easier to install.

#### 2.1 With **net-next-sim** (deprecated)

To build the liblinux.so, DCE version of Linux kernel,

```
make defconfig ARCH=sim
make library ARCH=sim
```

You can use `make menuconfig` command (below) instead of editing the defconfig file. If everything is fine, you will see `liblinux.so` linked to `libsim-linuxv.y.z.so` file at the root directory of Linux kernel.

```
make menuconfig ARCH=sim
```

#### 2.2 Build an MPTCP kernel with **net-next-sim**

DISCLAIMER: This is a transcript of Hajime’s guide https://plus.google.com/+HajimeTazaki/posts/1QUmR3n3vNA updated on a best effort basis. Hence it may be possible to compile newer versions, in which case patches are welcome. Build steps for DCE integration is also available as a script in `utils/mptcp-build.sh`.

1. Get linux kernel mptcp variant:

```
$ git clone mptcp_git_
$ git checkout -b sim3.14 mptcp_v0.89
```

1. Merge in mptcp code the changes required to make it work in DCE. Those changes are listed in the net-next-sim project

```
% cd mptcp
% git remote add dce git://github.com/direct-code-execution/net-next-sim.
% git fetch dce
% git fetch dce
% git merge dce/sim-ns3-3.14.0-branch
```

2. Enable mptcp in the kernel configuration. There are 2 ways possible:
• patch the kernel config manually (you can)

```bash
% cat >> arch/sim/defconfig <<END
CONFIG_MPTCP=y
CONFIG_MPTCP_PM_ADVANCED=y
CONFIG_MPTCP_FULLMESH=y
CONFIG_MPTCP_NDIFFPORTS=y
CONFIG_DEFAULT_FULLMESH=y
CONFIG_DEFAULT_MPTCP_PM="fullmesh"
CONFIG_TCP_CONG_COUPLED=y
CONFIG_TCP_CONG_OLIA=y
END
```

• or use menuconfig to enable these options as explained in http://multipath-tcp.org/pmwiki.php/Users/DoItYourself

```bash
% make menuconfig ARCH=sim
```

3. Generate the kernel configuration:

```bash
% make defconfig ARCH=sim
```

4. build kernel (as a shared library)

```bash
$ make library ARCH=sim
```

If everything is going well, you can try to use it over ns-3

1. build ns-3 related tools

```bash
% make testbin -C arch/sim/test
```

2. run an mptcp simulation!

```bash
% cd arch/sim/test/buildtop/source/ns-3-dce
% ./waf --run dce-iperf-mptcp
```

you should see generated *.pcap files in your dce folder.

2.3 With libos

Libos is the successor of net-next-sim. There are attempts to merge libos within the linux kernel library lkl project but it will take quite some time before being able to run lkl in DCE.

1. Get libos code:

```bash
$ git clone git@github.com:libos-nuse/net-next-nuse.git
$ git checkout libos-v4.4
$ cd net-next-nuse
```

2. Configure the kernel (you can refer to configure)

```bash
make defconfig ARCH=lib
```

3. Compile the kernel

```bash
make library ARCH=lib
```
This will download and compile git submodules from https://github.com/libos-nuse/linux-libos-tools and execute additional steps from the arch/lib/tools/Makefile, as for instance generate an additional libsim_linux.so. This is the shared library you need to load in DCE. By default DCE looks for “liblinux.so” so you should do:

```cpp
DceManagerHelper dceManager;
dceManager.SetNetworkStack ("ns3::LinuxSocketFdFactory", "Library", StringValue ("libsim-linux.so"));
```

3. Write user space application to use this protocol

Then, we need to write userspace applications using new feature of kernel protocol. In case of SCTP, we wrote sctp-client.cc and sctp-server.cc.

**Optional** You may optionally need external libraries to build/run the applications. In this case, the applications need lksctp-tools, so that applications fully benefit the features of SCTP, rather than only using standard POSIX socket API. Moreover, adding system dependency to bake configuration file (i.e., bakeconf.xml) would be nice to assist build procedure. The following is an example of lksctp-tools, which above applications use.

```xml
<module name="lksctp-dev">
  <source type="system_dependency">
    <attribute name="dependency_test" value="sctp.h"/>
    <attribute name="try_to_install" value="True"/>
    <attribute name="name_apt-get" value="lksctp-dev"/>
    <attribute name="name_yum" value="lksctp-tools-devel"/>
    <attribute name="more_information" value="Didn't find: lksctp-dev package; please install it."/>
  </source>
  <build type="none" objdir="no">
  </build>
</module>
```

4. Write ns-3 scenario to use above applications.

The next step would be writing ns-3 simulation scenario to use the applications you prepared. You need first to add to your DCE_PATH the path to the previously compiled liblinux.so:

```bash
:: $ export DCE_PATH="$HOME/net-next-sim:$DCE_PATH"
```

dce-sctp-simple.cc is the script that we prepared. In the script, you may need to load the applications by using DceApplicationHelper as follows.

```cpp
DceApplicationHelper process;
ApplicationContainer apps;

/* by default DCE, loads liblinux.so. If for some reason your library has a different name, 
   either create a symlink or use these commands to change the name */
DceManagerHelper dceManager;
dceManager.SetNetworkStack ("ns3::LinuxSocketFdFactory", "Library", StringValue ("liblinux.so"));

process.SetBinary ("sctp-server");
process.ResetArguments ();
process.SetStackSize (1<<16);
```
5. run it!

```
./waf --run dce-simple-sctp
```

If you're lucky, it's done.

If you aren't lucky, you may face errors of DCE, such as unresolved symbols in system calls (called by userspace applications) or missing kernel functions (used by newly added CONFIG_IP_SCTP option), or invalid memory access causing segmentation fault. In that case, adding missing functions, so called glue-code would be the next step.

### 3.2.3 How to add system calls?

**Introduction**

If your applications running with DCE are not able to run due to missing function symbols, you need to add the function call or system call to DCE by hand. The POSIX API coverage of DCE is growing day by day, but your contribution is definitely helpful not only for your case, but also for someone will use in future.

More specifically, if you faced the following error when you executed, you need to add a function call to DCE. In the following case, a symbol `strfry` not defined in DCE is detected during the execution of the simulation.

**Types of symbol**

There are two types of symbols that is defined in DCE.

- **NATIVE**
  
  NATIVE symbol is a symbol that DCE doesn’t care about the behavior. So this type of symbol is redirected to the one provided by underlying host operating system (i.e., glibc).

- **DCE**
  
  DCE symbol is a symbol that DCE reimplements its behavior instead of using the underlying system’s one. For instance, `socket()` call used in an application redirected to DCE to cooperate with *ns-3* or Linux network stack managed by DCE. `malloc()` is also this kind.

In general (but not strictly), if a call is related to a kernel resource (like NIC, clock, etc), it should use DCE macro. Otherwise (like strcmp, atoi etc), the call should use NATIVE.

**Files should be modified**

In order to add function calls or system calls that DCE can handle, you need to modify the following files.

- `model/libc-ns3.h`

---

3.2. Basic Use Cases 23
This is the first file that you need to edit. You may lookup the symbol that you're going to add and once you can't find it, add the following line.

NATIVE (strfry)

This is the case of the symbol strfry(), which we don’t have to reimplement. But you may need to add include file that defines the symbol (strfry()) at model/libc-dce.cc.

If the symbol needs to reimplemented for DCE, you may add as follows.

DCE (socket)

• model/dce-abc.cc

In case of DCE symbol, you’re going to introduce DCE redirected function. We use naming convention with prefix of dce_ to the symbol (i.e., dce_socket) to define new symbol and add the implementation in a .cc file. The following is the example of dce_socket() implementation.

We implemented dce_socket() function in the file model/dce-fd.cc.

    int dce_socket (int domain, int type, int protocol)

In the function, we carefully fill the function contents to cooperate with ns-3. The below line is creating DCE specific socket instance (i.e., ns-3 or DCE Linux) instead of calling system call allocating kernel space socket resources.

    UnixFd *socket = factory->CreateSocket (domain, type, protocol);

Other function calls such as file system related functions (e.g., read, fopen), time reheated features (e.g., gettimeofday, clock_gettime), signal/process utilities (e.g., getpid, sigaction), and thread library (e.g., pthread_create). All these functions should be DCE since DCE core reimplements these feature instead of using underlying host system.

• model/dce-abc.h

Once you got implemented the new redirected function, you may add the function prototype declaration to refer from other source files. dce_socket() is added to model/sys/dce-socket.h.

3.2.4 Creating your protocol implementation as a DCE sub-module

If your application has a configuration file to modify the behavior of applications, introducing a particular Helper class will be helpful to handle your application. In this section, we will give you an advanced way of using your application with DCE.

Some of existing submodule are following this way. You can find ns-3-dce-quagga and ns-3-dce-umip as examples to add sub-module.

Obtaining DCE sub-module template

First of all, you could start with referring sub module template available as follows.

    hg clone http://code.nsnam.org/thehajime/ns-3-dce-submodule (your module name)

The template consists of, wscript, helper, test and documentation. You could rename all/some of them for your module. Then, put ns-3-dce-submodule directory under ns-3-dce/myscripts/. This will be required to build under ns-3-dce module as an extension (sub-module) of dce.
Writing wscript

Writing bakeconf.xml (optional)

Implementing helper class (optional)

Writing examples (optional)

3.2.5 Global DCE Configurations

Parameters

The DCE specifics variables are essentially two PATH like variables: so within them you may put paths separated by ‘:’ character.

**DCE_PATH** is used by DCE to find the executable you want to launch within *ns-3* simulated network. This variable is used when you reference the executable using a relative form like ‘ping’.

**DCE_ROOT** is similar to **DCE_PATH** but it is used when you use an absolute form for example ‘/bin/bash’.

Please pay attention that executables that you will place in the directories indicated in the previous variables should be recompiled accordingly to the rules defined in the next chapter.

(TIXME: to be updated)

Tweaking

DCE is configurable with NS3 Attributes. Refer to the following table:

<table>
<thead>
<tr>
<th>ATTRIBUTE NAME</th>
<th>DESCRIPTION</th>
<th>VALUES</th>
<th>EXAMPLES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fibermanager-</td>
<td>The TaskMan-</td>
<td>UcontextFiberManager</td>
<td><strong>--ns3::TaskManager::FiberManagerType=UcontextFiberManager</strong></td>
</tr>
<tr>
<td>Type</td>
<td>ager is used</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>to switch</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>the execu-</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>tion context</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>between</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>threads and</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>processes.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Load-</td>
<td>The Loader-</td>
<td>CoojaLoaderFactory</td>
<td><strong>--ns3::DceManagerHelper::LoaderFactory=ns3::CoojaLoaderFactory</strong></td>
</tr>
<tr>
<td>erFactory</td>
<td>Factory is</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>used to load</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>the hosted</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>binaries.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>CoojaLoaderFactory</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>the default and the only one that</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>supports fork.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DlmLoaderFactory</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>is the more efficient. To use it you have two ways:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1/ use dce-runner 2/ link using ldso as default inter-</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>preter.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3.2. Basic Use Cases
3.2.6 DCE Cradle

This document describes what DCE Cradle is, how we can use it, how we extend it. Tutorials and how to reproduce the experiment of WNS3 2013 paper is available dce-cradle-usecase.

What is DCE Cradle?

DCE Cradle enables us to use Linux kernel via Direct Code Execution from the ns-3 native socket application. Applications can access it via ns-3 socket API. Currently (6th Jan. 2014) the following sockets are available:

- IPv4/IPv6 UDP
- IPv4/IPv6 TCP
- IPv4/IPv6 RAW socket
- IPv4/IPv6 DCCP
- IPv4/IPv6 SCTP

Installing DCE Cradle

DCE Cradle is already integrated in ns-3-dce module. You can just build and install DCE as instructed in the parent document.

How to use it

```c
OnOffHelper onoff = OnOffHelper ("ns3::LinuxTcpSocketFactory",
    InetSocketAddress (interfaces.GetAddress (1), 9));
```

How to extend it

(To be added)

Article

- The project originally started during GSoC project 2012
- “DCE cradle: simulate network protocols with real stacks for better realism”, WNS3 2013, [PDF]

3.2.7 Aspect-based Tracing

Aspect-based tracing, provided by libaspect, allows us to use tracing facility with unmodified code.

One of contradictions when we use DCE is, tracing, how to put trace sources into unmodified code. While DCE gives an opportunity to use unmodified codes as simulation protocols, one might want to investigate which function is called or how many messages of a particular protocol are exchanged.

ns-3 originally has a nice feature of tracing with such a purpose, with on-demand trace connector to obtain additional information. Instead of inserting TraceSource into the original code, DCE gives dynamic trace points with this library, based on the idea of aspect-based tracing.

For more detail, see the Chapter 6.3.2 of the thesis.
Quick Start

To put trace sources without modifying the original code, aspcpp::HookManager gives trace hooks into arbitrary source codes and functions.

```cpp
#include <hook-manager.h>

HookManager hooks;
hooks.AddHookBySourceAndFunction("ip_input.c", "::ip_rcv", &IpRcv);
hooks.AddHookByFunction("::process_backlog", &ProcBacklog);
hooks.AddHookByFunction("::arp_xmit", &ArpXmit);
```

The above examples specifies file name and functions with callback functions in the simulation script.

Limitations

- July 10th, 2013: aspect-based tracing (libaspect) is in the alpha release state. It might be updated frequently.
- Callback function has no argument that it can investigate the contents of buffer that each function handles.

3.2.8 FreeBSD kernel support with DCE

Overview

This module provides an additional network stack support for DCE with FreeBSD kernel.

- This is a POSIX userspace application support over FreeBSD kernel over DCE, over ns-3 over Linux.
- This is NOT the DCE running on FreeBSD operating system (right now DCE only run on Linux).

Usage

bake.py configure -e dce-freebsd-dev
bake.py download
bake.py build
Once you finished to build dce-freebsd module, you can write a simulation script that uses FreeBSD kernel as a network stack. All you need is to specify the library name with an attribute `Library` to `ns3::FreeBSDSocketFdFactory`, then install `FreeBSDStackHelper` to the nodes.

```cpp
DceManagerHelper processManager;
processManager.SetNetworkStack("ns3::FreeBSDSocketFdFactory",
    "Library", StringValue("libfreebsd.so"));
processManager.Install(nodes);
FreeBSDStackHelper stack;
stack.Install(nodes);
```

How to use your kernel extension with DCE?

No configuration support (like `make menuconfig` in Linux) right now. You need to add files into sys/sim/Makefile.

The following represents an example to add Multipath-TCP feature of FreeBSD by adding `mptcp_subr.o` to the freebsd-sim/sys/sim/Makefile. If you want to add your code into the kernel build, you may add object file names that is from your own codes.

```bash
diff --git a/sys/sim/Makefile b/sys/sim/Makefile
index 8115e3d..1b2feab 100644
--- a/sys/sim/Makefile
+++ b/sys/sim/Makefile
@@ -100,7 +100,7 @@ ip_divert.o tcp_hostcache.o ip_ecn.o tcp_input.o ip_encap.o
    tcp_lro.o ip_fastfwd.o tcp_offload.o ip_gre.o tcp_output.o ip_output.o tcp_usrreq.o raw_ip.o udp_usrreq.o if_llatbl.o
+    mptcp_subr.o
```

Limitations

While this release gives a proof of concept to use FreeBSD kernel with DCE, there are tons of limitations (listed below) that have to be improved in near future.

- No sysctl
- No IPv6 address configuration
- No ifconfig
- No delete IP addresses support
- No route command
- No quagga, new FreeBSD-version glue code needed
- No extensive test
- No DCE Cradle
- No Poll implementation
- No getifaddr/routing socket implementations
- Socket options missing (incosistent defined value: SOL_SOCKET(Linux/FreeBSD)=20/0xffff)
3.3 Advanced Use Cases

3.3.1 Using Alternative, Fast Loader

DCE optionally supports an alternative ELF loader/linker, so-called elf-loader, in order to replace system-provided linker/loader module. The intention of the loader is to support unlimited number of instances used by dlmopen call, which provides DCE to load a single ELF binary to multiple different memory space. dlmopen-based loader (ns3::DlmLoaderFactory) is much faster than another default one (ns3::CoojaLoaderFactory), but few issues are remain so, this is optional.

To Speedup Run-time

In order to use DlmLoaderFactory, you can add command-line argument of waf.

```
./waf --run dce-tcp-simple --dlm
```

if you are in the `./waf shell` mode, the following command should be used instead.

```
./build/bin/dce-runner ./build/bin/dce-tcp-simple
```

3.3.2 Tuning System Limits

When dealing with large or complex models, you can easily reach the limits of your system. For example, you cannot open more than a fixed number of files. You can try the command “limit –a” to check them.

File limits: “Could not open …”

You may see the following error:

```
msg="Could not open "/var"", file=../model/dce-manager.cc, line=149
terminate called without an active exception
```

This error masks error “24 Too many open files”. The cause of this is that the simulation process exceeded the limit of open files per process. Check the limit of open files per process with “ulimit -n” To solve it, you can edit file `/etc/security/limits.conf` and add the following lines at the end:

```
* hard nofile 65536
* soft nofile 65536
```

or

```
myuser  hard nofile 65536
myuser  soft nofile 65536
```
Processes limit: “Resource temporarily unavailable”

In this case you may see the an error like the following:

```
assert failed. cond="error == 0", msg="error=Resource temporarily unavailable",
file=../model/pthread-fiber-manager.cc, line=321
terminate called without an active exception
```

`pthread-fiber-manager` invokes `pthread_create` this is what raises the “Resource temporarily unavailable”. This problem might be triggered because the maximum number of user processes is not big enough. Use “`ulimit -u`” to check this limit. To solve it, you can edit file `/etc/security/limits.conf` and add the following lines at the end:

```
* hard nproc 65536
* soft nproc 65536
```

or

```
myuser hard nproc 65536
```

Stack size

DCE directly manages the stack of the processes running on it, assigning it a default value 8192. For complex executables this value is too small, and may raise ‘stack overflow’ exceptions, or in other cases it may originate inconsistent values. For example, a value passed to a function changes without apparent reason when the program enters in that function. The value of the stack size can be changed with the `SetStackSize` instruction:

```
DceApplicationHelper dce;
dce.SetStackSize (1<<20);
```

3.3.3 Debugging your protocols with DCE

Gdb

It is possible to use gdb to debug a script DCE/ns-3. As explained somewhere in the execution of a script is monoprocess, then you can put breakpoints in both sources of DCE and those of binaries hosted by DCE.

Install

Although it is not strictly necessary, it is recommended that you recompile a CVS Gdb for use with ns-3-dce. First, download:

```
cvs -d :pserver:anoncvs@sourceware.org:/cvs/src login {enter “anoncvs” as the password} cvs -d :pserver:anoncvs@sourceware.org:/cvs/src co gdb
```

Note that you might consider looking at http://sourceware.org/gdb/current/ to obtain more efficient (cpu/bandwidth-wise) download instructions.

Anyway, now, you can build:

```
  cd gdb
  ./configure
  make
```
And, then, invoke the version of gdb located in gdb/gdb instead of your system-installed gdb whenever you need to debug a DCE-based program.

**Using**

If you use gdb (a CVS or stable version), do not forget to execute the following command prior to running any DCE-based program:

```gdb
(gdb) handle SIGUSR1 nostop
Signal StopPrintPass to programDescription
SIGUSR1 NoYesYesUser defined signal 1
(gdb)
```

An alternate way to do this and avoid having to repeat this command ad-nauseam involves creating a .gdbinit file in your ns-3-dce directory and putting this inside:

```bash
handle SIGUSR1 nostop
```

or it can be put on the command line using the “-ex” flag:

```
./waf --run SCRIPT_NAME_HERE --command-template="gdb -ex 'handle SIGUSR1 nostop
→noprint' --args %s <args>"
```

**Setup Eclipse Remote Debugging Environment**

To remotely debug a DCE script you can use gdbserver as in the following example, changing the host name and port (localhost:1234):

```
./waf --run dce-httpd --command-template="gdbserver localhost:1234 %s <args>"
```

Then you can point a gdb client to your server. For example, in the following figure is reported an Eclipse debug configuration:

![Eclipse Debug Configuration](image)

Once you start the debug session, you can use the usual Eclipse/gdb commands.
Helpful debugging hints

There are a couple of functions which are useful to put breakpoints into:

- ns3::DceManager::StartProcessDebugHook

Put a breakpoint in a specific node in a simulation

If you got a trouble in your protocol during interactions between distributed nodes, you want to investigate a specific state of the protocol in a specific node. In a usual system, this is a typical case of using distributed debugger (e.g., ddt, or mpirun xterm -e gdb --args xxx), but it is annoying task in general due to the difficulty of controlling distributed nodes and processes.

DCE gives an easy interface to debug distributed applications/protocols by the single-process model of its architecture.

The following is an example of debugging Mobile IPv6 stack (of Linux) in a specific node (i.e., home agent). A special function `dce_debug_nodeid()` is useful if you put a break condition in a gdb session.

```gdb
(gdb) b mip6_mh_filter if dce_debug_nodeid()==0
Breakpoint 1 at 0x7ffff287c569: file net/ipv6/mip6.c, line 88.
<continue>
(gdb) bt 4
#0  mip6_mh_filter (sk=0x7ffff7f69e10, skb=0x7fffff7cde8b0) at net/ipv6/mip6.c:109
#1  0x00007fffff2831418 in ipv6_raw_deliver (skb=0x7fffff7cde8b0, nexthdr=135) at net/ipv6/raw.c:199
#2  0x00007fffff2831697 in raw6_local_deliver (skb=0x7fffff7cde8b0, nexthdr=135) at net/ipv6/raw.c:232
#3  0x00007fffff27e6068 in ip6_input_finish (skb=0x7fffff7cde8b0) at net/ipv6/ip6_input.c:197
(More stack frames follow...)
```

Valgrind

(FIXME: simple session using valgrind)

3.3.4 Testing your protocols with DCE

Since DCE allows protocol implementations to expose network conditions (packet losses, reordering, and errors) with the interactions among distributed nodes, which is not easily available by traditional user-mode virtualization tools, exercising your code is easily done with a single simulation script.

Coverage Test

Improving code coverage with writing test programs is one of headache: - writing test program is annoying, - preparing test network tends to be short-term, and - the result is not reproducible.

This text describes how to measure code coverage of protocol implementations with DCE.

1. build target implementations (applications, kernel stack) with profile option
2. run test program with DCE
3. parse the result of test coverage

**Setup**

First, you need to compile your application with additional flags. `-fprofile-arcs -ftest-coverage` is used for a compilation flag (CFLAGS/CXXFLAGS), and `-fprofile-arcs` is used for a linker flag (LDFLAGS).

```bash
gcc -fprofile-arcs -ftest-coverage -fPIC -c foo.c
gcc -fprofile-arcs -pie -rdynamic foo.o -o newapp
```

**Write Test Program**

Next, write a test program like ns-3 simulation script for your application (i.e., newapp).

```cpp
$ cat myscripts/dce-newapp.cc

int main (int argc, char *argv[]) {
    CommandLine cmd;
    cmd.Parse (argc, argv);

    NodeContainer nodes;
    nodes.Create (2);

    InternetStackHelper stack;
    stack.Install (nodes);

    DceManagerHelper dceManager;
    dceManager.Install (nodes);

    DceApplicationHelper dce;
    ApplicationContainer apps;

    // application on node 0
    dce.SetBinary ("newapp");
    dce.ResetArguments();
    apps = dce.Install (nodes.Get (0));
    apps.Start (Seconds (4.0));

    // application on node 1
    dce.SetBinary ("newapp");
    dce.ResetArguments();
    apps = dce.Install (nodes.Get (1));
    apps.Start (Seconds (4.5));

    Simulator::Stop (Seconds(100.0));
    Simulator::Run ();
    Simulator::Destroy ();

    return 0;
}
```
### Run Test

Then, test your application as normal *ns-3* (and DCE) simulation execution.

```
./waf --run dce-newapp
```

If you successfully finish your test, you will see the coverage data files (i.e., gcov data files) with a file extension `.gcda`.

```
$ find ./ -name "*.gcda"
```

```
./files-0/home/you/are/here/ns-3-dce/newapp.gcda
./files-1/home/you/are/here/ns-3-dce/newapp.gcda
```

### Parse Test Result

We use `lcov` utilities as a parse of coverage test result.

Put the compiler (gcc) generated files (*`.gcno`) in the result directory,

```
cp *.gcno ./files-0/home/you/are/here/ns-3-dce/
cp *.gcno ./files-1/home/you/are/here/ns-3-dce/
```

then run the `lcov` and `genhtml` command to generate coverage information of your test program.

```
lcov -c -d . -b . --output-file test.info
genhtml test.info -o html
```

You will see the following output and generated html pages.

```
Reading data file test.info
Found 8 entries.
Writing .css and .png files.
Generating output.
Processing file ns-3-dce/example/udp-server.cc
genhtml: Use of uninitialized value in subtraction (−) at /usr/bin/genhtml line 4313.
Processing file ns-3-dce/example/udp-client.cc
genhtml: Use of uninitialized value in subtraction (−) at /usr/bin/genhtml line 4313.
Processing file /usr/include/c++/4.4/iostream
Processing file /usr/include/c++/4.4/ostream
Processing file /usr/include/c++/4.4/bits/ios_base.h
Processing file /usr/include/c++/4.4/bits/locale_facets.h
Processing file /usr/include/c++/4.4/bits/char_traits.h
Processing file /usr/include/c++/4.4/bits/basic_ios.h
Writing directory view page.
Overall coverage rate:
  lines.......: 49.3% (35 of 71 lines)
  functions...: 31.6% (6 of 19 functions)
```
3.4 Technical Information

3.4.1 DCE in a Nutshell

File System

To start a program in the world of ns-3 you must indicate on which node it will be launched. Once launched this program will have access only to the file system corresponding to the node that corresponds to a directory on your machine called file-X where X is the decimal number of the corresponding node. The file-X directories are created by DCE, only when they do not already exist. Also note that the contents of this directory is not cleared when starting the script. So you can copy the files required for the operation of your executables in the tree nodes. If possible it is best that you create these files from the script itself in order to simplify maintenance. DCE provides some helpers for creating configuration files necessary to the execution of certain apps like CCNx and Quagga.

Network

Your program running in a ns-3 node views the network defined by the script for this node.
Time

Time perceived by your executable is the simulated time of *ns-3*. Also note that DCE supports real time scheduler of *ns-3* with the same limitations.

### 3.4.2 Limitations

- Currently the POSIX API (libc) is not fully supported by DCE. However there are already about **400 methods** supported. As the goal of DCE is to allow to execute network applications, many methods related to the network are supported for example *socket, connect, bind, listen, read, write, poll, select*. The next chapter list the applications well tested using DCE.
- Some methods are not usable with all options of DCE. For more details refer to chapter *Coverage API* that lists all the supported methods.
- The scheduler is not as advanced as that of a kernel, for example if an infinite loop in a hosted application, DCE can not get out, but this should not happen in applications written correctly.

### 3.4.3 API Coverage

Below there is the list of the systems calls supported by DCE, the column named **Type** represents how the system call is implemented ie:

1. **DCE** the method is fully rewritten,
2. **NATIVE** the real corresponding system call is used.

<table>
<thead>
<tr>
<th>System Call Name</th>
<th>Domain</th>
<th>Include file</th>
<th>Type</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>gettimeofday</td>
<td>Date &amp; Time</td>
<td>sys/time.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>time</td>
<td>Date &amp; Time</td>
<td>time.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>asctime, ctime, gmtime, localtime</td>
<td>Date &amp; Time</td>
<td>time.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>asctime_r, ctime_r, gmtime_r, localtime_r, mktime, strftime</td>
<td>Date &amp; Time</td>
<td>time.h</td>
<td>DCE</td>
<td>Should not be NATIVE, do not use for now.</td>
</tr>
<tr>
<td>clock_gettime</td>
<td>Date &amp; Time</td>
<td>time.h</td>
<td>NATIVE</td>
<td></td>
</tr>
<tr>
<td>read</td>
<td>IO</td>
<td>unistd.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>write</td>
<td>IO</td>
<td>unistd.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>writev</td>
<td>IO</td>
<td>sys/uio.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>clearerr</td>
<td>IO</td>
<td>stdio.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>setbuf, setbuffer, setlinebuf, setbuf</td>
<td>IO</td>
<td>stdio.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>fseek, ftell, rewind, fgetpos, fsetpos</td>
<td>IO</td>
<td>stdio.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>printf</td>
<td>IO</td>
<td>stdio.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>fprintf, snprintf</td>
<td>IO</td>
<td>stdio.h</td>
<td>NATIVE</td>
<td></td>
</tr>
<tr>
<td>sprintf, vasprintf</td>
<td>IO</td>
<td>stdio.h</td>
<td>NATIVE</td>
<td></td>
</tr>
<tr>
<td>dprintf, vdprintf</td>
<td>IO</td>
<td>stdio.h</td>
<td>NATIVE</td>
<td></td>
</tr>
<tr>
<td>fgetc, fgetc_unlocked</td>
<td>IO</td>
<td>stdio.h</td>
<td>DCE</td>
<td></td>
</tr>
</tbody>
</table>

Continued on next page
<table>
<thead>
<tr>
<th>System Call Name</th>
<th>Domain</th>
<th>Include file</th>
<th>Type</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>getc, getc_unlocked</td>
<td>IO</td>
<td>stdio.h</td>
<td>Native</td>
<td></td>
</tr>
<tr>
<td>getchar, getchar_unlocked</td>
<td>IO</td>
<td>stdio.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>_IO_getc</td>
<td>IO</td>
<td>stdio.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>fputc, fputc_unlocked</td>
<td>IO</td>
<td>stdio.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>putc, putc_unlocked</td>
<td>IO</td>
<td>stdio.h</td>
<td>Native</td>
<td></td>
</tr>
<tr>
<td>putchar, putchar_unlocked</td>
<td>IO</td>
<td>stdio.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>_IO_putchar</td>
<td>IO</td>
<td>stdio.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>fgets, fgets_unlocked</td>
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<td>stdio.h</td>
<td>DCE</td>
<td></td>
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<tr>
<td>fputs, f.puts_unlocked</td>
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<td>stdio.h</td>
<td>DCE</td>
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<tr>
<td>puts</td>
<td>IO</td>
<td>stdio.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>ungetc</td>
<td>IO</td>
<td>stdio.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>fclose</td>
<td>IO</td>
<td>stdio.h</td>
<td>DCE</td>
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<td>fcloseall</td>
<td>IO</td>
<td>stdio.h</td>
<td>DCE</td>
<td></td>
</tr>
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<td>fopen, fdopen64, fdopen, fopen</td>
<td>IO</td>
<td>stdio.h</td>
<td>DCE</td>
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<tr>
<td>fflush, fflush_unlocked</td>
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<td>stdio.h</td>
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<td></td>
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<tr>
<td>fread, fread_unlocked</td>
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<td>stdio.h</td>
<td>DCE</td>
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<tr>
<td>fwrite, fwrite_unlocked</td>
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<td>stdio.h</td>
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<tr>
<td>ferror, ferror_unlocked</td>
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<tr>
<td>feof, feof_unlocked</td>
<td>IO</td>
<td>stdio.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>fileno, fileno_unlocked</td>
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<td>stdio.h</td>
<td>DCE</td>
<td></td>
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<tr>
<td>perror</td>
<td>IO</td>
<td>stdlib.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>vprintf</td>
<td>IO</td>
<td>stdarg.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>vfprintf, vsprintf, vsnprintf</td>
<td>IO</td>
<td>stdarg.h</td>
<td>Native</td>
<td></td>
</tr>
<tr>
<td>fcntl</td>
<td>IO</td>
<td>fcntl.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>dup, dup2</td>
<td>IO</td>
<td>unistd.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>open, open64</td>
<td>IO</td>
<td>fcntl.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>close</td>
<td>IO</td>
<td>unistd.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>unlink</td>
<td>IO</td>
<td>unistd.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>remove</td>
<td>IO</td>
<td>stdio.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>mkdir</td>
<td>IO</td>
<td>sys/stat.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>rmdir</td>
<td>IO</td>
<td>unistd.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>select</td>
<td>IO</td>
<td>unistd.h</td>
<td>DCE</td>
<td></td>
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<td>isatty</td>
<td>IO</td>
<td>unistd.h</td>
<td>DCE</td>
<td></td>
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<tr>
<td>ioctl</td>
<td>IO</td>
<td>sys/ioct.h</td>
<td>DCE</td>
<td></td>
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<tr>
<td>poll</td>
<td>IO</td>
<td>poll.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>getcwd, getwd, get_current_dir_name</td>
<td>IO</td>
<td>unistd.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>chdir, fchdir</td>
<td>IO</td>
<td>unistd.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>alphasort, alphasort64, versionsort</td>
<td>IO</td>
<td>dirent.h</td>
<td>Native</td>
<td></td>
</tr>
<tr>
<td>umask</td>
<td>IO</td>
<td>sys/stat.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>truncate, ftruncate</td>
<td>IO</td>
<td>unistd.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>ttyname</td>
<td>IO</td>
<td>unistd.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>lseek</td>
<td>IO</td>
<td>unistd.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>euidaccess, eaccess</td>
<td>IO</td>
<td>unistd.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>pathconf</td>
<td>IO</td>
<td>unistd.h</td>
<td>Native</td>
<td></td>
</tr>
<tr>
<td>getpwnam, getpwuid, endpwent</td>
<td>IO</td>
<td>pwd.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>opendir, fdopendir</td>
<td>IO</td>
<td>dirent.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>readdir, readdir_r</td>
<td>IO</td>
<td>dirent.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>closedir</td>
<td>IO</td>
<td>dirent.h</td>
<td>DCE</td>
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</table>

**Table 3.1 – continued from previous page**
<table>
<thead>
<tr>
<th>System Call Name</th>
<th>Domain</th>
<th>Include file</th>
<th>Type</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>dirfd</td>
<td>IO</td>
<td>dirent.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>rewinddir</td>
<td>IO</td>
<td>dirent.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>scandir</td>
<td>IO</td>
<td>dirent.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>unlinkat</td>
<td>IO</td>
<td>fcntl.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>pread, pwrite</td>
<td>IO</td>
<td>unistd.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>uname</td>
<td>Kernel</td>
<td>sys/utsname.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>sysconf</td>
<td>Kernel</td>
<td>unistd.h</td>
<td>NATIVE</td>
<td></td>
</tr>
<tr>
<td>calloc, malloc, free, realloc</td>
<td>Memory Allocation</td>
<td>stdlib.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>mmap, mmap64, munmap</td>
<td>Memory Mappings</td>
<td>sys/map.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>htonl</td>
<td>Networking</td>
<td>arpa/inet.h</td>
<td>NATIVE</td>
<td></td>
</tr>
<tr>
<td>htons</td>
<td>Networking</td>
<td>arpa/inet.h</td>
<td>NATIVE</td>
<td></td>
</tr>
<tr>
<td>ntohl</td>
<td>Networking</td>
<td>arpa/inet.h</td>
<td>NATIVE</td>
<td></td>
</tr>
<tr>
<td>htonl</td>
<td>Networking</td>
<td>arpa/inet.h</td>
<td>NATIVE</td>
<td></td>
</tr>
<tr>
<td>socket</td>
<td>Networking</td>
<td>sys/socket.h</td>
<td>DCE</td>
<td>Not all flavour are supported please look at the doxygen doc.</td>
</tr>
<tr>
<td>getsockname</td>
<td>Networking</td>
<td>sys/socket.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>getpeername</td>
<td>Networking</td>
<td>sys/socket.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>bind</td>
<td>Networking</td>
<td>sys/socket.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>connect</td>
<td>Networking</td>
<td>sys/socket.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>inet_aton, inet_addr, inet_network, inet_ntoa, inet_makeaddr, inet_lnaof, inet_netof</td>
<td>Networking</td>
<td>arpa/inet.h</td>
<td>NATIVE</td>
<td></td>
</tr>
<tr>
<td>inet_ntop</td>
<td>Networking</td>
<td>arpa/inet.h</td>
<td>NATIVE</td>
<td></td>
</tr>
<tr>
<td>getprotoent, getprotobyname, getprotobyname2, getprotoent, endprotoent</td>
<td>Networking</td>
<td>netdb.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>gethostbyname, gethostbyname2</td>
<td>Networking</td>
<td>netdb.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>getaddrinfo, freaddrinfo, gai_strerror</td>
<td>Networking</td>
<td>netdb.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>gethostent, gethostent, gethostentset, hstrerror</td>
<td>Networking</td>
<td>netdb.h</td>
<td>NATIVE</td>
<td></td>
</tr>
<tr>
<td>herror</td>
<td>Networking</td>
<td>netdb.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>getprotoent, getprotobyname, getprotoent, getprotoent, endprotoent</td>
<td>Networking</td>
<td>netdb.h</td>
<td>NATIVE</td>
<td></td>
</tr>
<tr>
<td>getservent, getservbyname, getservbyport, setservent, endservent</td>
<td>Networking</td>
<td>netdb.h</td>
<td>NATIVE</td>
<td></td>
</tr>
<tr>
<td>if_nametoindex</td>
<td>Networking</td>
<td>net/if.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>getnameinfo</td>
<td>Networking</td>
<td>sys/socket.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>ether_aton_r</td>
<td>Networking</td>
<td>net/ether.h</td>
<td>NATIVE</td>
<td></td>
</tr>
<tr>
<td>atexit</td>
<td>Process</td>
<td>stdlib.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>getpid, getppid</td>
<td>Process</td>
<td>unistd.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>getuid, geteuid</td>
<td>Process</td>
<td>unistd.h</td>
<td>DCE</td>
<td></td>
</tr>
</tbody>
</table>

Continued on next page
<table>
<thead>
<tr>
<th>System Call Name</th>
<th>Domain</th>
<th>Include file</th>
<th>Type</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>setuid</td>
<td>Process</td>
<td>unistd.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>setgid</td>
<td>Process</td>
<td>unistd.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>seteuid, setegid</td>
<td>Process</td>
<td>unistd.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>setreuid, setregid</td>
<td>Process</td>
<td>unistd.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>setresuid, setresgid</td>
<td>Process</td>
<td>unistd.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>sched_yield</td>
<td>Process</td>
<td>sched.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>exit</td>
<td>Process</td>
<td>unistd.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>getenv</td>
<td>Process</td>
<td>stdlib.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>putenv</td>
<td>Process</td>
<td>stdlib.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>setenv, unsetenv</td>
<td>Process</td>
<td>stdlib.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>clearenv</td>
<td>Process</td>
<td>stdlib.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>fork</td>
<td>Process</td>
<td>unistd.h</td>
<td>DCE</td>
<td>Supported only with the Cooja Loader.</td>
</tr>
<tr>
<td>abort</td>
<td>Process</td>
<td>stdlib.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>execl, execlp, execle, execv, execvp, execve</td>
<td>Process</td>
<td>unistd.h</td>
<td>DCE</td>
<td>Supported only with the pthread fiber manager.</td>
</tr>
<tr>
<td>wait, waitpid</td>
<td>Process</td>
<td>sys/wait.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>sbrk</td>
<td>Process</td>
<td>unistd.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>getpagesize</td>
<td>Process</td>
<td>unistd.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>getgid, getegid</td>
<td>Process</td>
<td>unistd.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>gethostname</td>
<td>Process</td>
<td>unistd.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>getpgrp</td>
<td>Process</td>
<td>unistd.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>pipe</td>
<td>Process</td>
<td>unistd.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>__sigsetjmp, siglongjmp</td>
<td>Process</td>
<td>setjmp.h</td>
<td>NATIVE</td>
<td>Experimental, please do not use them.</td>
</tr>
<tr>
<td>getdtablesize</td>
<td>Process</td>
<td>unistd.h</td>
<td>NATIVE</td>
<td></td>
</tr>
<tr>
<td>random, srandom</td>
<td>Random</td>
<td>stdlib.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>rand, srand</td>
<td>Random</td>
<td>stdlib.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>drand48, erand48, lrand48, nrand48, mrand48, jrand48, srand48, seed48, lcong48</td>
<td>Random</td>
<td>stdlib.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>drand48_r, erand48_r, lrand48_r, nrand48_r, mrand48_r, jrand48_r, srand48_r, seed48_r, lcong48_r</td>
<td>Random</td>
<td>stdlib.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>signal</td>
<td>Signal</td>
<td>signal.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>sigaction</td>
<td>Signal</td>
<td>signal.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>sigemptyset, sigfillset, sigaddset, sigdelset, sigismember</td>
<td>Signal</td>
<td>signal.h</td>
<td>NATIVE</td>
<td></td>
</tr>
<tr>
<td>sigprocmask</td>
<td>Signal</td>
<td>signal.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>qsort</td>
<td>Sort</td>
<td>stdlib.h</td>
<td>NATIVE</td>
<td></td>
</tr>
<tr>
<td>strerror, strerror_h</td>
<td>String</td>
<td>string.h</td>
<td>NATIVE</td>
<td></td>
</tr>
<tr>
<td>setlocale</td>
<td>String</td>
<td>locale.h</td>
<td>DCE</td>
<td>Do nothing at all</td>
</tr>
<tr>
<td>strcoll</td>
<td>String</td>
<td>string.h</td>
<td>NATIVE</td>
<td></td>
</tr>
<tr>
<td>uselocale</td>
<td>String</td>
<td>locale.h</td>
<td>NATIVE</td>
<td></td>
</tr>
<tr>
<td>newlocale</td>
<td>String</td>
<td>locale.h</td>
<td>NATIVE</td>
<td></td>
</tr>
<tr>
<td>wctob</td>
<td>String</td>
<td>wchar.h</td>
<td>NATIVE</td>
<td></td>
</tr>
<tr>
<td>btowc</td>
<td>String</td>
<td>wchar.h</td>
<td>NATIVE</td>
<td></td>
</tr>
<tr>
<td>memset</td>
<td>String</td>
<td>string.h</td>
<td>NATIVE</td>
<td></td>
</tr>
<tr>
<td>memcpy</td>
<td>String</td>
<td>string.h</td>
<td>NATIVE</td>
<td></td>
</tr>
<tr>
<td>bcopy</td>
<td>String</td>
<td>string.h</td>
<td>NATIVE</td>
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<table>
<thead>
<tr>
<th>System Call Name</th>
<th>Domain</th>
<th>Include File</th>
<th>Type</th>
<th>Remarks</th>
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<tr>
<td>memcmp</td>
<td>String</td>
<td>string.h</td>
<td>NATIVE</td>
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<td>memmove</td>
<td>String</td>
<td>string.h</td>
<td>NATIVE</td>
<td></td>
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<tr>
<td>memchr</td>
<td>String</td>
<td>string.h</td>
<td>NATIVE</td>
<td></td>
</tr>
<tr>
<td>strcpy, strncpy</td>
<td>String</td>
<td>string.h</td>
<td>NATIVE</td>
<td></td>
</tr>
<tr>
<td>strcat, strncat</td>
<td>String</td>
<td>string.h</td>
<td>NATIVE</td>
<td></td>
</tr>
<tr>
<td>strcmp, strncmp</td>
<td>String</td>
<td>string.h</td>
<td>NATIVE</td>
<td></td>
</tr>
<tr>
<td>strlen, strnlen</td>
<td>String</td>
<td>string.h</td>
<td>NATIVE</td>
<td></td>
</tr>
<tr>
<td>strspn, strcspn</td>
<td>String</td>
<td>string.h</td>
<td>NATIVE</td>
<td></td>
</tr>
<tr>
<td>strchr, strrchr</td>
<td>String</td>
<td>string.h</td>
<td>NATIVE</td>
<td></td>
</tr>
<tr>
<td>strcasecmp, strncasecmp</td>
<td>String</td>
<td>string.h</td>
<td>NATIVE</td>
<td></td>
</tr>
<tr>
<td>strdup, strndup</td>
<td>String</td>
<td>string.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>getopt, getopt_long</td>
<td>String</td>
<td>unistd.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>atoi, atol, atoll, atof</td>
<td>String</td>
<td>stdlib.h</td>
<td>NATIVE</td>
<td></td>
</tr>
<tr>
<td>strtol, strtoull</td>
<td>String</td>
<td>stdlib.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>strtoimax, strtoomax</td>
<td>String</td>
<td>inttypes.h</td>
<td>NATIVE</td>
<td></td>
</tr>
<tr>
<td>getlog, syslog, closelog, vsyslog, setlogmask</td>
<td>Syslog</td>
<td>syslog.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>pthread_create</td>
<td>Thread</td>
<td>pthread.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>pthread_exit</td>
<td>Thread</td>
<td>pthread.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>pthread_self</td>
<td>Thread</td>
<td>pthread.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>pthread_once</td>
<td>Thread</td>
<td>pthread.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>pthread_getspecific, pthread_setspecific</td>
<td>Thread</td>
<td>pthread.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>pthread_key_create</td>
<td>Thread</td>
<td>pthread.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>pthread_key_delete</td>
<td>Thread</td>
<td>pthread.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>pthread_mutex_destroy, pthread_mutex_init</td>
<td>Thread</td>
<td>pthread.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>pthread_mutex_lock, pthread_mutex_trylock, pthread_mutex_unlock</td>
<td>Thread</td>
<td>pthread.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>pthread_mutexattr_destroy, pthread_mutexattr_init</td>
<td>Thread</td>
<td>pthread.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>pthread_mutexattr_settype</td>
<td>Thread</td>
<td>pthread.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>pthread_cancel</td>
<td>Thread</td>
<td>pthread.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>pthread_join</td>
<td>Thread</td>
<td>pthread.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>pthread_detach</td>
<td>Thread</td>
<td>pthread.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>pthread_cond_destroy, pthread_cond_init</td>
<td>Thread</td>
<td>pthread.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>pthread_cond_broadcast, pthread_cond_signal</td>
<td>Thread</td>
<td>pthread.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>pthread_cond_timedwait, pthread_cond_wait</td>
<td>Thread</td>
<td>pthread.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>pthread_condattr_destroy, pthread_condattr_init</td>
<td>Thread</td>
<td>pthread.h</td>
<td>DCE</td>
<td></td>
</tr>
</tbody>
</table>

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Table 3.1 – continued from previous page

<table>
<thead>
<tr>
<th>System Call Name</th>
<th>Domain</th>
<th>Include file</th>
<th>Type</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>sem_init</td>
<td>Thread</td>
<td>semaphore.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>sem_destroy</td>
<td>Thread</td>
<td>semaphore.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>sem_post</td>
<td>Thread</td>
<td>semaphore.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>sem_wait, sem_trywait, sem_timedwait</td>
<td>Thread</td>
<td>semaphore.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>sem_getvalue</td>
<td>Thread</td>
<td>semaphore.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>sleep, usleep</td>
<td>Timer</td>
<td>unistd.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>nanosleep</td>
<td>Timer</td>
<td>time.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>getitimer, setitimer</td>
<td>Timer</td>
<td>sys/time.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>timerfd_create, timerfd_settime, timerfd_gettime</td>
<td>Timer</td>
<td>sys/time.h</td>
<td>DCE</td>
<td></td>
</tr>
<tr>
<td>getgrnam</td>
<td>Users &amp; Groups</td>
<td>grp.h</td>
<td>NATIVE</td>
<td></td>
</tr>
<tr>
<td>getrusage</td>
<td>Users &amp; Groups</td>
<td>sys/resource</td>
<td>NATIVE</td>
<td></td>
</tr>
</tbody>
</table>

### 3.5 DCE Python Scripts

Currently DCE includes an experimental support to the Python language. To enable it, you may need to recompile it with the flags:

```bash
--with-pybindgen=HERE_THE_PYBINDGEN_PATH
```

indicating the path to an existing Pybindgen source tree to use. Or in case waf didn’t find the interpreter, you can try to use the flags:

```bash
--with-python=HERE_THE_PYTHON_PATH
```

The first thing you may want to do is to import the DCE module. For example a minimal DCE script in Python could be:

```python
from ns.DCE import *
print "It works!"
```
3.5.1 A first example

In this example, DCE executes a program running ten seconds on a single node.

```python
# DCE import
from ns.DCE import *
# ns-3 imports
import ns.applications
import ns.core
import ns.network

# Increase the verbosity level
ns.core.LogComponentEnable("Dce", ns.core.LOG_LEVEL_INFO)
ns.core.LogComponentEnable("DceManager", ns.core.LOG_LEVEL_ALL)
ns.core.LogComponentEnable("DceApplication", ns.core.LOG_LEVEL_INFO)
ns.core.LogComponentEnable("DceApplicationHelper", ns.core.LOG_LEVEL_INFO)

# Node creation
nodes = ns.network.NodeContainer()
nodes.Create(1)

# Configure DCE
dceManager = ns.DCE.DceManagerHelper()
dceManager.Install (nodes);
dce = ns.DCE.DceApplicationHelper()

# Set the binary
dce.SetBinary ("tenseconds")
dce.SetStackSize (1<<20)
# dce.Install returns an instance of ns.DCE.ApplicationContainer
apps = dce.Install (nodes )
apps.Start ( ns.core.Seconds (4.0))

# Simulation
ns.core.Simulator.Stop (ns.core.Seconds(20.0))
ns.core.Simulator.Run ()
ns.core.Simulator.Destroy ()
print "Done."
```

You can then run the example with “waf –pyrun ...”

```
./waf --pyrun PATH_TO_YOUR_SCRIPT_HERE
```

or attach gdb to the python script:

```
./waf shell
gdb python -ex "set args PATH_TO_YOUR_SCRIPT_HERE" -ex "handle SIGUSR1 nostop noprint"
```

3.5.2 Limitations

The DCE Python bindings does not currently match completely the C++ API of DCE. The following classes are supported:
<table>
<thead>
<tr>
<th>Class</th>
<th>Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>DceApplication</td>
<td>GetPid, SetArguments, SetBinary, SetEgid, SetEnvironment, SetEuid, SetGid, SetStackSize, SetStdinFile, SetUid</td>
</tr>
<tr>
<td>DceApplication-Helper</td>
<td>AddArgument, AddArguments, AddEnvironment, Install, InstallInNode, ParseArguments, ResetArguments, ResetEnvironment, SetBinary, SetEgid, SetEuid, SetGid, SetStackSize, SetStdinFile, SetUid, GetPid</td>
</tr>
<tr>
<td>ProcStatus</td>
<td>GetCmdLine, GetExitCode, GetNode, GetPid, GetRealDuration, GetRealEndTime, GetRealStartTime, GetSimulatedDuration, GetSimulatedEndTime, GetSimulatedStartTime</td>
</tr>
<tr>
<td>DceManager-Helper</td>
<td>GetProcStatus, GetVirtualPath, Install, SetAttribute, SetVirtualPath</td>
</tr>
<tr>
<td>Ipv4DceRoutingHelper</td>
<td>Copy, Create</td>
</tr>
<tr>
<td>LinuxStack-Helper</td>
<td>Install, InstallAll, RunIp, SetRoutingHelper, SysctlGet, SysctlSet</td>
</tr>
</tbody>
</table>
This document is for the people who want to develop DCE itself.

4.1 Kernel Developer Information

This technical documentation is intended for developers who want to build a Linux kernel in order to use with DCE. A first part will describe the architecture and the second will show how we went from a net-next kernel 2.6 has a Linux kernel-stable 3.4.5.

4.1.1 Prerequisite

You must be familiar with ns-3, DCE and Linux Kernel Development.

4.1.2 Download

The source code can be found in the following repository: http://code.nsnam.org/furbani/ns-3-linux. You must use mercurial to download the source code.

4.1.3 Goal

The goal of this work is to use the real implementation of the Linux Network Stack within the Simulation environment furnished by ns-3.

4.1.4 Solution

The solution chosen was to use the Linux kernel source, compile the Net part and make a dynamic library and interface the result with DCE.

The following schema shows the different parts between a software user space application and the hardware network.
The following schema show the same application running under DCE and ns-3 and using a real kernel network stack:
The green parts are implemented in ns-3-linux source files, the grays parts comes from the Linux kernel sources and are not modified at all or with only few changes. Application should not be modified at all.

### 4.1.5 Concepts

If you need a more theoretical documentation you can read the chapter 4.5 of this Ph.D. thesis *Experimentation Tools for Networking Research*.

### 4.1.6 List of files and usage

After doing the cloning of the source,

```bash
$ hg clone http://code.nsnam.org/furbani/ns-3-linux
destination directory: ns-3-linux
requesting all changes
adding changesets
adding manifests
adding file changes
added 62 changesets with 274 changes to 130 files
updating to branch default
125 files updated, 0 files merged, 0 files removed, 0 files unresolved
```

Below are the files delivered under the directory `ns-3-linux`:

```bash
$ ls ns-3-linux/
generate-autoconf.py  generate-linker-script.py  kernel-dsmip6.patch  kernel.patch
Makefile  Makefile.print  processor.mk  README  sim
```
The main file is the **Makefile** its role is to recover the kernel source, compile the NET part of the kernel and all that is necessary for the operation, the end result is a shared library that can be loaded by DCE.

```shell
$ ls ns-3-linux/sim
cred.c  glue.c  Kconfig  pid.c  random.c  seq.c  sim-socket.c
softirq.c  tasklet.c  timer.c
defconfig  hrtimer.c  Makefile  print.c  sched.c  sim.c  slab.c
--sysctl.c  tasklet-hrtimer.c  workqueue.c
fs.c  include  modules.c  proc.c  security.c  sim-device.c  socket.c
--sysfs.c  time.c
$ ls ns-3-linux/sim/include
asm  generated  sim-assert.h  sim.h  sim-init.h  sim-printf.h  sim-types.h
```

These directories contains the architecture specific code and the code doing the interface between the kernel and DCE and **ns-3**. Ideally we should not change a line of code outside the kernel arch portion, but in practice we make small changes : see the patches files.

Recall: the code of Linux source is mainly C so it is very easy to port to new architecture, the architecture specific code is contained in a specific directory under arch/XXX directory where XXX name recall the processor used. In our case we have chosen to create a special architecture for our environment NS3 + DCE, we called **sim**.

### 4.1.7 Interfaces between Kernel and DCE

In order to install a kernel on a Node DCE do the following steps:

1. Load the shared library containing the kernel compilation result,
2. Call the init function called **sim_init**, this method is located in the just loaded library,
3. This **sim_init** method is called with a parameter which is a struct containing functions pointers to DCE methods able to be callable from the kernel part,
4. in return the **sim_init** fill a struct containing function pointers in kernel part which will be used by DCE to interact with the kernel part.
5. before finish **sim_init** must initialize the kernel to put it in a running state ready to be usable.

**Kernel -> DCE**

Methods (there is also one variable) of DCE called by the kernels are the following:

- LinuxSocketFdFactory::Vprintf
- LinuxSocketFdFactory::Malloc
- LinuxSocketFdFactory::Free
- LinuxSocketFdFactory::Memcpy
- LinuxSocketFdFactory::Memset
- LinuxSocketFdFactory::Random
- LinuxSocketFdFactory::EventScheduleNs
- LinuxSocketFdFactory::EventCancel
- CurrentNs
• LinuxSocketFdFactory::TaskStart
• LinuxSocketFdFactory::TaskWait
• LinuxSocketFdFactory::TaskCurrent
• LinuxSocketFdFactory::TaskWakeup
• LinuxSocketFdFactory::TaskYield
• LinuxSocketFdFactory::DevXmit
• LinuxSocketFdFactory::SignalRaised
• LinuxSocketFdFactory::PollEvent

there are located in the source file `linux-socket-fd-factory.cc` of DCE.

**DCE -> Kernel**

Methods of Kernel (sim part) called by DCE are the following:

• task_create
• task_destroy
• task_get_private
• sock_socket
• sock_close
• sock_recvmsg
• sock_sendmsg
• sock_getsockname
• sock_getpeername
• sock_bind
• sock_connect
• sock_listen
• sock_shutdown
• sock_accept
• sock_ioctl
• sock_setsockopt
• sock_getsockopt
• sock_poll
• sock_pollfreewait
• dev_create
• dev_destroy
• dev_get_private
• dev_set_address
• dev_set_mtu
• dev_create_packet
• dev_rx
• sys_iterate_files
• sys_file_read
• sys_file_write

the corresponding sources are located in the sim directory.

4.1.8 Build net-next 2.6 kernel

All build operations are done using the make command with the Makefile file under the directory ns-3-linux.

Make Setup

First you should call make setup in order to download the source of the kernel:

```
$ make setup
```

```
git clone git://git.kernel.org/pub/scm/linux/kernel/git/davem/net-next.git net-next-2.6; 
   cd net-next-2.6 && git reset --hard fed66381d65a35198639f564365e61a7f256bf79
Cloning into net-next-2.6...
remote: Counting objects: 2441000, done.
remote: Compressing objects: 100% (377669/377669), done.
Receiving objects: 100% (2441000/2441000), 493.28 MiB | 28.45 MiB/s, done.
remote: Total 2441000 (delta 2043525), reused 2436782 (delta 2039307)
Resolving deltas: 100% (2043525/2043525), done.
Checking out files: 100% (33319/33319), done.
```

This sources correspond to a specific version well tested with DCE the net-next 2.6 and git tag = fed66381d65a35198639f564365e61a7f256bf79.

Now the directory net-next-2.6 contains the kernel sources.

Make Menuconfig

Use make menuconfig to configure your kernel, note that modules are not supported by our architecture so options chosen as modules will not be included in the result kernel.

Build

Finally make will compile all the needed sources and produce a file named libnet-next-2.6.so: this is the library contains our net-next kernel suitable for DCE usage.

Usage

To use this kernel you should:

1. configure DCE in order to compile using the includes under sim directories to have the good interfaces between DCE and the kernel. For this you should give to the waf configure the path to the ns-3-linux directory i.e.:
2. In your ns-3 scenario you should indicate the good kernel file: (the file should be located in a directory presents in the DCE_PATH env. variable)

dceManager.SetNetworkStack("ns3::LinuxSocketFdFactory", "Library",
                        StringValue ("libnet-next-2.6.so"));

Test

Use DCE unit test:

```bash
$ ./waf --run "test-runner --verbose"
```

<table>
<thead>
<tr>
<th>Test Case</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>process-manager</td>
<td>9.470ms</td>
</tr>
<tr>
<td>Check that process &quot;test-empty&quot; completes correctly</td>
<td>0.920ms</td>
</tr>
<tr>
<td>Check that process &quot;test-sleep&quot; completes correctly</td>
<td>0.080ms</td>
</tr>
<tr>
<td>Check that process &quot;test-pthread&quot; completes correctly</td>
<td>0.110ms</td>
</tr>
<tr>
<td>Check that process &quot;test-mutex&quot; completes correctly</td>
<td>0.200ms</td>
</tr>
<tr>
<td>Check that process &quot;test-once&quot; completes correctly</td>
<td>0.070ms</td>
</tr>
<tr>
<td>Check that process &quot;test-pthread-key&quot; completes correctly</td>
<td>0.070ms</td>
</tr>
<tr>
<td>Check that process &quot;test-sem&quot; completes correctly</td>
<td>0.080ms</td>
</tr>
<tr>
<td>Check that process &quot;test-malloc&quot; completes correctly</td>
<td>0.060ms</td>
</tr>
<tr>
<td>Check that process &quot;test-malloc-2&quot; completes correctly</td>
<td>0.060ms</td>
</tr>
<tr>
<td>Check that process &quot;test-fd-simple&quot; completes correctly</td>
<td>0.070ms</td>
</tr>
<tr>
<td>Check that process &quot;test-strerror&quot; completes correctly</td>
<td>0.070ms</td>
</tr>
<tr>
<td>Check that process &quot;test-stdio&quot; completes correctly</td>
<td>0.240ms</td>
</tr>
<tr>
<td>Check that process &quot;test-string&quot; completes correctly</td>
<td>0.060ms</td>
</tr>
<tr>
<td>Check that process &quot;test-netdb&quot; completes correctly</td>
<td>3.940ms</td>
</tr>
<tr>
<td>Check that process &quot;test-env&quot; completes correctly</td>
<td>0.050ms</td>
</tr>
<tr>
<td>Check that process &quot;test-cond&quot; completes correctly</td>
<td>0.160ms</td>
</tr>
<tr>
<td>Check that process &quot;test-timer-fd&quot; completes correctly</td>
<td>0.060ms</td>
</tr>
<tr>
<td>Check that process &quot;test-stdlib&quot; completes correctly</td>
<td>0.060ms</td>
</tr>
<tr>
<td>Check that process &quot;test-fork&quot; completes correctly</td>
<td>0.120ms</td>
</tr>
<tr>
<td>Check that process &quot;test-select&quot; completes correctly</td>
<td>0.320ms</td>
</tr>
<tr>
<td>Check that process &quot;test-nanosleep&quot; completes correctly</td>
<td>0.070ms</td>
</tr>
<tr>
<td>Check that process &quot;test-random&quot; completes correctly</td>
<td>0.090ms</td>
</tr>
<tr>
<td>Check that process &quot;test-local-socket&quot; completes correctly</td>
<td>0.820ms</td>
</tr>
<tr>
<td>Check that process &quot;test-poll&quot; completes correctly</td>
<td>0.320ms</td>
</tr>
<tr>
<td>Check that process &quot;test-exec&quot; completes correctly</td>
<td>0.380ms</td>
</tr>
<tr>
<td>Check that process &quot;test-iperf&quot; completes correctly</td>
<td>0.070ms</td>
</tr>
<tr>
<td>Check that process &quot;test-name&quot; completes correctly</td>
<td>0.080ms</td>
</tr>
<tr>
<td>Check that process &quot;test-pipe&quot; completes correctly</td>
<td>0.160ms</td>
</tr>
<tr>
<td>Check that process &quot;test-dirent&quot; completes correctly</td>
<td>0.070ms</td>
</tr>
<tr>
<td>Check that process &quot;test-socket&quot; completes correctly</td>
<td>0.270ms</td>
</tr>
<tr>
<td>Check that process &quot;test-bug-multi-select&quot; completes correctly</td>
<td>0.260ms</td>
</tr>
<tr>
<td>Check that process &quot;test-tsearch&quot; completes correctly</td>
<td>0.080ms</td>
</tr>
</tbody>
</table>

All is OK.

### 4.1.9 net-next 2.6 to linux-stable 3.4.5

Now we will try to use a more recent linux kernel. We start with a fresh clone of the ns-3-linux sources.
Makefile

First we need to modify the makefile in order to change the kernel downloaded. For that we need to modify the value of 2 variables:

1. KERNEL_DIR=linux-stable
2. KERNEL_VERSION=763c71b1319c56272e42cf6ada6994131f0193a7

Also we need to remove the patch target named .target.ts because the patch will not pass for this newer version of kernel.

First Build

Now we can try to build:

```
$ make defconfig
$ make menuconfig
$ make
mkdir -p sim
cc -O0 -g3 -D__KERNEL__ -Wall -Wstrict-prototypes -Wno-trigraphs -fno-inline \ 
  -iwithprefix ./linux-stable/include -DKBUILD_BASENAME="clnt" \ 
  -fno-strict-aliasing -fno-common -fno-delete-null-pointer-checks \ 
  -fno-stack-protector -DKBUILD_MODNAME="nsc" -DMODVERSIONS \ 
  -DEXPORT_SYMTAB -include autoconf.h -U_FreeBSD__ -D__linux__=1 \ 
  -Dlinux=1 -D__linux=1 -I./sim/include -I./linux-stable/include \ 
  -fpic -DPIC -D_DEBUG \ 
  -I/home/furbani/dev/dce/dev/etude_kernel/V3/ns-3-linux \ 
  -DCONFIG_64BIT -c sim/fs.c -o sim/fs.o
```

Ok now we will try to fix the compilation errors trying not to change too the kernel source. In the following we will list the main difficulties encountered.
First Error

Recall: the linux source directory include/asm-generic contains a C reference implementation of some code that should be written in assembly language for the target architecture. So this code is intended to help the developer to port to new architectures. So our sim implementation uses many of these asm-generic include files. The first warning shows that our code redefine a method defined elsewhere in kernel sources, so the fix is to remove our definition of this function in our file named sim/include/asm/irqflags.h.

Second Error

The file asm/barrier.h is missing, we just create under sim/include/asm directory and the implementation is to include the generic one ie: include/asm-generic/barrier.h.

Change in sim method

Another problem arise the function named kern_mount_data defined in sim/fs.c do not compile any more. So we need to investigate about this function:

1. Where this function is located in the real code: in linux/fs/namespace.c
2. Why it is reimplemented in sim/fs.c: if you look at our Makefile why try to not compile all the kernel we focus on the net part only, you can see this line in the Makefile:

```
dirs=kernel/ mm/ crypto/ lib/ drivers/base/ drivers/net/ net/
```

in fact we include only this directories. So at this time we can comment the failing line and insert a sim_assert (false); in order to continue to fix the compilation errors, and then when we will do the first run test we will see if this method is called and if yes we will need to do a better fix. Remark: sim_assert (false); is a macro used to crash the execution, we often place it in functions that we need to emulate because required by the linker but that should never be called.

Change in our makefile

After we have the following problem while compiling sim/glue.c the macro IS_ENABLED is not defined. After some search we found that we need to include linux/kconfig.h in many files. So we modify our makefile to fix like this:

```
fno-stack-protector \n-fDDBUILD_MODNAME="\nsim\n" -DMODVERSIONS -DEXPORT_SYMTAB \n-include autoconf.h " \n+ -include $(SRCDIR)$(KERNEL_DIR)/include/linux/kconfig.h \n-__FreeBSD__ -D__linux__=1 -Dlinux=1 -D__linux=1 \n-I$(SRCDIR)sim/include -I$(SRCDIR)$(KERNEL_DIR)/include \n$(AUTOCONF): generate-autoconf.py $(KERNEL_DIR)/.config timeconst.h .generate-autoconf.py $(KERNEL_DIR)/.config > $@ \n+ cp autoconf.h sim/include/generated/autoconf.h \n+ perl $(SRCDIR)$(KERNEL_DIR)/kernel/timeconst.pl $(CONFIG_HZ) > $@
```

Change in kernel source

Our sim/slab.c do not compile, in this case we want to use our implementation of memory allocation and to do this it is easier to modify slightly an include file in the kernel sources include/linux/slab.h:
As we have already written we do not recommend to change the kernel sources to facilitate future upgrades.

First Launch

After a few corrections we finally get a library containing the kernel named `liblinux-stable.so`. At this moment we need to try it using DCE. For the beginning we will try with test-runner executable.

```
./test.py
assert failed. cond="handle != 0", msg="Could not open elf-cache/0/libnet-next-2.6.so →
elf-cache/0/liblinux-stable.so: undefined symbol: noop_llseek", file=../model/cooja-
loader-factory.cc, line=225
```

We can see that a symbol is not defined: `noop_llseek`. We find this symbol defined in the kernel source named `fs/read_write.cc`. We need to choose a way to add this symbol in our kernel library, we can:

- rewrite it in a source under our sim directory,
- or add it in our makefile.

In this case we choose the second solution so we need to modify our makefile, first we see that the directory `fs` is not present in the `dirs` entry, so we need to add it in the write order (order is the same as found in the kernel Makefile defined by the variable named `vmlinux-main`); we also need to indicate that we want only the object `read_write.o`:

```
@@ -51,7 +52,7 @@
 AUTOCONF=autoconf.h
 # note: the directory order below matters to ensure that we match the kernel order
 -dirs=kernel/ mm/ crypto/ lib/ drivers/base/ drivers/net/ net/
+dirs=kernel/ mm/ fs/ crypto/ lib/ drivers/base/ drivers/net/ net/
   empty:=
   space:= $(empty) $(empty)
   colon:= :
@@ -67,11 +68,12 @@
 ctype.o string.o kasprintf.o rbtree.o shal.o textsearch.o vsprintf.o \
 rwsem-spinlock.o scatterlist.o ratelimit.o hexdump.o dec_and_lock.o \
 div64.o
+fs/_to_keep=read_write.o
```

Fake Function

We continue to try our kernel library, now another symbol is missing `generic_file_aio_read`, this symbol is defined in the source `mm/filemap.cc`, it is referenced at least by `read_write.c`. In this case we decided to create a fake function because the source `mm/filemap.cc` is voluminous and we do not want to take all the kernel sources. So we create a
new source under sim directory named sim/filemap.c the body of the function is sim_assert (false); so if this function called sometimes we will be warned and we will write a more accurate version.

**Assert**

Later we meet again the function kern_mount_data, thanks to the presence of the sim_assert:

```c
0x000000000a0795c7 in kern_mount_data (fs=<optimized out>, data=<optimized out>) at sim/fs.c:52
  sim_assert (false);
(gdb) bt
#0 0x000000000a0795c7 in kern_mount_data (fs=<optimized out>, data=<optimized out>) at sim/fs.c:52
#1 0x000000000a0795c7 in kern_mount_data (fs=<optimized out>, data=<optimized out>) at sim/fs.c:169
#2 0x000000000a0795c7 in sim_init (exported=<optimized out>, imported=<optimized out>, kernel=<optimized out>) at sim/sim.c:169
#3 0x000000000a0795c7 in sim_init (exported=<optimized out>, imported=<optimized out>, kernel=<optimized out>) at sim/sim.c:169
#4 0x000000000a0795c7 in sim_init (exported=<optimized out>, imported=<optimized out>, kernel=<optimized out>) at sim/sim.c:169
#5 0x000000000a0795c7 in sim_init (exported=<optimized out>, imported=<optimized out>, kernel=<optimized out>) at sim/sim.c:169
#6 0x000000000a0795c7 in sim_init (exported=<optimized out>, imported=<optimized out>, kernel=<optimized out>) at sim/sim.c:169
#7 0x000000000a0795c7 in sim_init (exported=<optimized out>, imported=<optimized out>, kernel=<optimized out>) at sim/sim.c:169
#8 0x000000000a0795c7 in sim_init (exported=<optimized out>, imported=<optimized out>, kernel=<optimized out>) at sim/sim.c:169
#9 0x000000000a0795c7 in sim_init (exported=<optimized out>, imported=<optimized out>, kernel=<optimized out>) at sim/sim.c:169
#10 0x000000000a0795c7 in sim_init (exported=<optimized out>, imported=<optimized out>, kernel=<optimized out>) at sim/sim.c:169
```

So this function is called by the initialisation, we must provide an implementation for it:

**Listing 4.1: Implementation taken from vfs_kern_mount from linux/namespace.c**

```c
struct vfsmount *kern_mount_data(struct file_system_type *type, void *data)
{
    static struct mount local_mnt;
    struct mount *mnt = &local_mnt;
    struct dentry *root = 0;

    memset (mnt, 0, sizeof (struct mount));
    if (!type)
        return ERR_PTR(-ENODEV);
    int flags = MS_KERNMOUNT;
    char *name = type->name;
    if (flags & MS_KERNMOUNT)
        mnt->mnt.mount_flags = MNT_INTERNAL;

    root = type->mount(type, flags, name, data);
    if (IS_ERR(root)) {
        return ERR_CAST(root);
    }

    mnt->mnt.mnt_root = root;
    mnt->mnt.mnt_sb = root->d_sb;
    mnt->mnt.mountpoint = mnt->mnt.mnt_root;
}
```

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mnt->mnt_parent = mnt;
// br_write_lock(vfsmount_lock); DCE is monothreaded, so we do not care of lock here
list_add_tail(&mnt->mnt_instance, &root->d_sb->s_mounts);
// br_write_unlock(vfsmount_lock); DCE is monothreaded, so we do not care of lock here
return &mnt->mnt;
}

Here we do not want to integrate all the code namespace.c, so we copy and paste the function named kern_mount_data. This solution has the advantage of minimizing code size, the disadvantage is that it can introduce problems if the next version of the kernel need changes in this function.

### 4.1.10 Conclusion

We will not describe the rest of the port here. But after some iteration we end up with a version that works correctly. Sometimes we should not hesitate to use gdb to trace the actual execution and correct accordingly code. The rules that we can gain from this experience’s are as follows:

1. Be patient,
2. Try to not modify the kernel sources,
3. Be pragmatic,
4. Try to not import all the kernel code into our library,
5. Do not hesitate to go back and test other alternatives.

### 4.2 DCE - POLL IMPLEMENTATION

#### 4.2.1 Introduction

The implementation of the poll system call is inspired by the Linux kernel, therefore we well study first the kernel poll implementation.

**Kernel implementation**

Firstly in the kernel every type of file descriptor (file, socket, pipe ...) must provide a function named poll and conform to this prototype:

```c
int poll(struct file *file, poll_table *pwait);
```

Where file is a pointer to a structure representing the file (it looks like this in C++) and pwait is a pointer to a poll table. pwait may be NULL, we will see later why. The return integer of this function is a mask of poll events which have already occured on the corresponding file descriptor. The behavior of this function is as follows: 1. It is not a blocking function, it immediately returns the mask of events regardless of event desired by the caller of poll. 2. if pwait is not NULL then it add pwait in the wait queue of file, and secondly a pointer to the wait queue is stored in the poll table pwait.

Thus an event on the file will ascend to the poll, and in the opposite direction when the poll ends it can de-register itself from the wait queue of the file.
Now that we know the function `poll` of `file`, we can study the `poll` system call, here the following pseudo code commented:

```c
POLL( ..., )
{
    poll_table table; // This table will contain essentially the list of wait queues
    →that need to wake me,
    // and also information about the current thread in order to be awakened.
    poll_table *pwait=&table; // pointer to current poll table.

    while (true)
    {
        foreach( fd ) // For each file descriptor ...
        {
            file *file = get_file(fd); // Retrieve **file** data structure
            →corresponding to fd.

            if (!file)
                mask = POLLNVAL; // fd does not correspond to an open file.
            else
                mask = file->poll (file, pwait); // During the first loop pwait is not NULL.

            if (mask)
            {
                count++; // Increases the number of responses
                pwait = NULL; // Once we have at least one response POLL should not be blocking,
                // so we nullify the pointer to the poll table in order to
                // not register the poll table to more file descriptors.
            }
        }
        pwait = NULL; // For the next loops we must not re-register to the wait queue
                       // of files.

        if (count) break; // we have a result.
        if (timeout) break; // it is too late.

        Wait(timeout); // Put to sleep until awakening from a file or because of the time limit.
    }
    poll_freewait(&table); // Removes the reference to the poll table from each file's
                          →wait queue.

    return count;
}
```

**DCE implementation**

As we have already seen, the poll will look like that of the kernel. Firstly we create a virtual method named Poll in the class UnixFd. This method will do the same job that the function `poll` seen early in the struct file of the kernel linux implementation. Before writing the function `dce_poll` which is our implementation of poll we need to create some classes for mimic the role of the poll table and the wait queues.

So we add 2 sources files named wait-queue.h and wait-queue.cc in order to implements poll table and wait queue.

It is also on this occasion that I deleted all the objects used to wait which was allocated on the stack, and I replaced by
objects allocated in the heap. Concerning the dce-poll function it looks like the kernel one with some differences. The more important difference is that the PollTable cannot be allocated on the stack so it cannot be a local variable, so the PollTable object is allocated with a C++ new. I guess you’re wondering why the poll table cannot be allocated on the stack, it is because of the fork implementation of DCE. Indeed, if a process makes a fork, this creates another stack which use the same memory addresses, thus another thread of the same process cannot use an object allocated on this stack, and when a event of a file want to wake up the poll thread it will use especially this poll table. So allocating the Poll Table in the heap generates a side effect which is that we need to release this memory if another thread call exit while we are within the dce-poll. So we need to register the Poll Table somewhere in a DCE data, and the DCE place choosen is the thread struct (in file model/process.h), because each thread can be in doing a poll. Thus there is a new field in struct thread which is:

```
PollTable *pollTable; // No 0 if a poll is running on this thread
```

There is another reason to have this field, this reason arises from the fact that a file descriptor can be shared by multiple processes (thanks to dup fork ...), thus when a process exit while doing a poll, we need to deregister from the corresponding wait queues referred by the poll table.

**Poll kernel implementation**

Concerning the kernel implementation the dce-poll method is the same but the difference comes from the Poll method specialized implementation of the class inherited from UnixFd and which correspond to a File Descriptor open with the help of the Kernel Linux. For example the class LinuxSocketFd represents a socket which is opened in the kernel, therefore the method poll of LinuxSocketFdFactory will do much work.

Now look at the interface between DCE and the kernel, in the direction DCE to kernel, we use 2 functions which are sock_poll and sock_pollfreewait, and in the other direction there is sim_poll_event. sock_poll obviously has the same semantics as the kernel poll. sock_poll has the following signature:

```
void sock_poll (struct SimSocket *s, void *ret);
```

where s represents the socket int the kernel and ret is a pointer to a data structure of type struct poll_table_ref:

```
struct poll_table_ref
{
    int ret;
    void *opaque;
};
```

This structure allows the kernel to pass a reference to the poll table DCE via the opaque field. This reference will be used by the kernel only to warn DCE that event just happened on socket, this using the function sim_poll_event (void *ref). In return this function modifies the value of opaque and assign it a pointer to a core structure which represents an entry in the wait queue of the socket. This value will be used by DCE for unregister it from the wait queue using the function sock_pollfreewait function (void * ref). The field ret is also affected in return and it contain the mask of poll events which have already occurred on the corresponding socket. Most of the kernel code is in the file sim-socket.c it consists of two structures, and the following functions:
### NAME | DESCRIPTION
--- | ---
sim_pollwakeup | Function called by the kernel when the arrival of an event on the socket, if the event is expected by DCE, the function forwards it to DCE.
sim_pollwait | Function called by the kernel, its role is to register the poll table in the wait queue.
sim_sock_poll | Function called by DCE, it is the interface between the DCE’s poll and the kernel’s poll.
sim_sock_pollfreewait | Function called by DCE allows it to unregister from the wait queue.
struct poll_table_ref | This is the same struct as that of DCE.
struct sim_ptable_entry | This is used for the entry in the wait queue of the socket.

# TODO add example, gdb breakpoint to follow the behavior in live

### 4.3 Python Bindings

This section describes how generate the DCE Python bindings. The intended audience are the DCE developers, not the users willing to make simulations. People not interested in adding new public API can ignore this section, and read the chapter DCE Python Scripts.

Waf configuration scripts generate the Python bindings in a semi-automatic way. They use PyBindGen to generate a Python script template. This script needs to be manually updated. This intermediate script will generate a C++ source file that can be then compiled as a shared object, installed and imported by the Python scripts.

#### 4.3.1 Step by Step

**Step 1: Api scan**

In this step, Waf calls PyBindGen to analyze the DCE public reference headers, in order to generate a temporary template Python file, that will generate a C++ file.

```
./waf --apiscan
```

**Step 2: Pybindgen script update**

The Python script generated in the first step needs to be adjusted and renamed as ns3_module_dce.py. In particular to reduce the coupling with the ns-3 installation the waf configuration has been simplified. For this reason you need to paste the correct references for the ns-3 exported symbols, as for example:

```python
module.add_class('Object', import_from_module='ns.core')
module.add_class('Node', import_from_module='ns.network')
module.add_class('NodeContainer', import_from_module='ns.network')
```

**Step 3: C++ source code generation**

ns3_module_dce.py can directly generate a C++ file for the Python module: ns3_module_dce.cpp. It should be added to the code revision system and included in the distribution. It just requires an installed recent version of Pybindgen.

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Step 4: Compilation

In the compilation phase, *wscript* (the Waf installation module), compiles *ns3_module_dce.cpp* and generate a shared object called *dce.so*. This is the Python binding module.

```bash
./waf
./waf install
```

### 4.3.2 Configuration parameters

waf configuration flags:

- **--disable-python** Don’t build Python bindings.
- **--apiscan** Rescan the API for Python bindings. Needs working GCCXML / pygccxml environment.
- **--with-pybindgen=WITH_PYBINDGEN** Path to an existing Pybindgen source tree to use.
- **--with-python=WITH_PYTHON** Path to an existing Pyhton installation
If you are interested to know why DCE exists and how it can work, you should read this document Experimentation Tools for Networking Research (and in particular the chapter 4) written by the principal author of DCE, Mathieu Lacage. Also you can read the sources too.

5.1 Introduction

You know that the goal of DCE is to execute actual binaries within ns-3. More precisely a binary executed by DCE perceives time and space of ns-3, rather than the real environment.

To do this, DCE does a job equivalent to an operating system like:

1. DCE loads in memory the code and data of executable,
2. DCE plays the role of intermediary between the executable and the environment through the systems functions called by executables,
3. DCE manages and monitors the execution of processes and handles liberate the memory and close open files when the stop process.
4. DCE manages the scheduling of the various virtual processes and threads.

5.2 Main classes and main data structures

5.2.1 DceManager

The DceManager is somewhat the entry point of DCE. It will create virtual processes and manages their execution. There is an instance of DceManager which is associated to each node which need to virtualize the execution of a process. In reality, the developer uses the classes DceManagerHelper and DceApplicationHelper.

I invite you to look at the source code dce-manager.cc and dce-manager.h and particularly the public methods Start, Stop, Exit, Wakeup, Wait and Yield; the following private methods are also important: CreateProcess, PrepareDoStartProcess, DoStartProcess, AllocatePid, TaskSwitch, CleanupThread and LoadMain. The Start method is called when starting the executable, if you look at, it begins by initializing an object of type struct Process. struct Process is very important, it contains information about the virtual processes that DCE creates, this type is described below. Start then also initializes a structure of type struct thread, it represents the principal thread in which the main entry of the executable will run. Finally Start asks the TaskManager to create a new Task and to start this one using the method DceManager::DoStartProcess as the entry point.

Class TaskManager is a major class of DCE, it is described below.
5.2.2 Process

struct process contains everything you need to describe a process, I invite you to study the source code in the file process.h.

This structure contains references to standard objects for example a list of open files via a vector of FILE *, but it contains also the references to objects useful to manage DCE threads, the memory allocated by the process...

Field openFiles represents the open file descriptors of the process, the key is the fd and the value a pointer to an object of type DCE FileUsage. The field threads contains all the threads in the process see description below. Field loader is a pointer to the Loader used to load the corresponding code.

The alloc field is important it is a pointer to the memory allocator used to allocate the memory used by this process, at the end of the process it will liberate all the memory allocated so as simple and efficient.

5.2.3 Thread

struct thread represents a thread. It contains various fields including a pointer to the process to which it belongs, and also a pointer to Task object described later.

5.2.4 Taskmanager and Task

The TaskManager manages the Tasks, ie the threads of virtualized processes by DCE. It allows you to create new task. It controls the activity of the task by the following methods: Stop, Wakeup, Sleep and Yield. A Task possesses a stack which contains the call stack functions. There is one instance of TaskManager per node. The implementation of TaskManager is based on a class of type FiberManager described below.

5.2.5 FiberManager

FiberManager actually implements the creation of the execution contexts. These contexts are called fiber. FiberManager offers the following:

1. Create a context, it returns a fiber
2. Delete a fiber
3. Yield hand to another fiber

DCE provides two implementations:

1. PthreadFiberManager, which is based on the pthread library,
2. UcontextFiberManager which is based on the POSIX API functions offered by ucontext.h: makecontext, getcontext and setcontext.

I invite you to watch the corresponding man.

5.2.6 LoaderFactory and Loader

The Loader is a very important object of DCE. A DCE Loader loads the executable code in memory of a special way, load several times the same executable, while isolating each of the other executable. The Loader must link the executable loaded with the 3 emulated libraries, i.e., lib C, lib pthread and lib rt. The same way the libraries used by the executable must also be linked with the emulated libraries.

DCE offers several actually Loader:
1. **CoojaLoader**: it has the following characteristics: it loads into memory only a copy of the code, by cons it duplicates data (i.e., global variables and static). For each change of context there are 2 memory copies: backup data of the current context then restoration of context memory that will take control. Comment: it is rather reliable, the size of the copied memory size depends on the total static and global variables, and in general there is little, in a well-designed executable.

2. **DlmLoader**: Uses a specialized loader to not duplicate the code but only the data but without special operations to do when changing context. Comment: offers the best performance in memory and cpu, but not very reliable especially during the unloading phase.

### 5.3 Follow a very simple example

After theory, do a bit of practice. Follow the execution of very simple example.

You can find the used sample under the directory named `myscripts/sleep`. This executable used by the scenario do only a sleep of ten seconds:

```c
#include <unistd.h>

int main(int c, char **v)
{
    sleep (10);
    return 1;
}
```

The *ns-3/DCE* scenario execute **tenseconds** one time starting at time zero:

```c
#include "ns3/core-module.h"
#include "ns3/dce-module.h"

using namespace ns3;

int main (int argc, char *argv[])
{
    NodeContainer nodes;
    nodes.Create (1);

    DceManagerHelper dceManager;
    dceManager.Install (nodes);

    DceApplicationHelper dce;
    ApplicationContainer apps;

    dce.SetStackSize (1<<20);
    dce.SetBinary ("tenseconds");
    dce.ResetArguments ();
    apps = dce.Install (nodes.Get (0));
    apps.Start (Seconds (0.0));

    Simulator::Stop (Seconds(30.0));
    Simulator::Run ();
    Simulator::Destroy ();
}
```

---

5.3. **Follow a very simple example**
First we can launch the binary with $ ./build/bin_dce/tenseconds. After ~10 seconds you retrieve the prompt.

Then we can try the DCE scenario: .. code-block:: sh

$ ./build/myscripts/sleep/bin/dce-sleep

This time the test is almost instantaneous, because the scenario is very simple and it uses the simulated time.

Same test by activating logs:

Listing 5.1: Log messages generated by dce-sleep

We can see that an event occurs at 30s it is the end of the simulation corresponding to the line:

Simulator::Stop (Seconds(30.0));

We can also see that at 10s an event occurs, this is the end of our `sleep(10)`.

Now we do the same experiment using the debugger:

Listing 5.2: a GNU debugger session on dce-sleep binary
You can notice that:

1. We have two breakpoints.
2. After run the first stop is in `ns3::DceManager::Start`.
3. At this time there is only one thread.
4. We are currently processing an event, this event was scheduled by the call `apps.Start (Seconds (0.0))` of our scenario.

Now we continue our execution:

```
(gdb) continue
Continuing.
[New Thread 0x7fff65fc700 (LWP 8159)]
[Switching to Thread 0x7fff65fc700 (LWP 8159)]
Breakpoint 3, ns3::DceManager::DoStartProcess (context=0x633d50) at ../model/dce-manager.cc:274
274 Thread *current = (Thread *)context;
(gdb) info thread
Id   Target Id   Frame
*  2 Thread 0x7fff6600740 (LWP 7977) "dce-sleep" ns3::DceManager::Start
   (this=0x630c50, .... ) at ../model/dce-manager.cc:403
```

You can notice that:

1. Now there is a second thread
2. Gdb break execution in `ns3::DceManager::DoStartProcess` in the context of the second thread

This second thread is the thread corresponding to the main thread of our hosted executable `tenseconds`, if you look at `ns3::DceManager::DoStartProcess` you can notice that we are on the point of calling the main of `tenseconds`:

```
(gdb) bt
# 0 ns3::DceManager::DoStartProcess (context=0x633d50) at ../model/dce-manager.cc:274
# 1 0x000007fff7d21b90 in ns3::TaskManager::Trampoline (context=0x633bd0) at ../model/task-manager.cc:267
# 2 0x000007fff7d21a78 in ns3::PthreadFiberManager::Run (arg=0x634040) at ../model/pthread-fiber-manager.cc:402
# 3 0x000000034be206cc in start_thread (arg=0x7fff665fc700) at pthread_create.c:301
# 4 0x000000034bd6e0c2d in clone () at sysdeps/unix/sysv/linux/x86_64/clone.S:115
```

5.3. Follow a very simple example

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Listing 5.3: Source code that calls program’s main function

```c
void
DceManager::DoStartProcess (void *context)
{
    Thread *current = (Thread *)context;
    int (*main)(int, char ***) = PrepareDoStartProcess (current);
    int retval = 127;

    if (main)
    {
        StartProcessDebugHook ();
        retval = main (current->process->originalArgc, current->process->originalArgv);
    }
    dce_exit (retval);
}
```

You can also see that the pointer to the main is the result of the method `ns3::DceManager::PrepareDoStartProcess`. Now we can put a breakpoint before the sleep of `tenseconds` and follow the code of sleep:

```c
(gdb) break tensconds.c:5
(gdb) continue
Breakpoint 1, main (c=1, v=0x630b30) at ../myscripts/sleep/tenseconds.c:5
5   sleep (10);
```

```c
(gdb) list
(gdb) step
sleep () at ../model/libc-ns3.h:193
193 DCE (sleep)
(gdb) step
dce_sleep (seconds=10) at ../model/dce.cc:226
226 Thread *current = Current ();
(gdb) list
224 unsigned int dce_sleep (unsigned int seconds)
225 {
226    Thread *current = Current ();
227    NS_LOG_FUNCTION (current << UtilsGetNodeId ());
228    NS_ASSERT (current != 0);
229    current->process->manager->Wait (Seconds (seconds));
230    return 0;
231 }
```

```c
(gdb) bt
#0 dce_sleep (seconds=10) at ../model/dce.cc:226
#1 0x000006d62c3b9 in sleep () at ../model/libc-ns3.h:193
#2 0x000006d6536f25 in main (c=1, v=0x630b30) at ../myscripts/sleep/tenseconds.c:5
#3 0x000006d679b0bb in ns3::DceManager::DoStartProcess (context=0x633d50) at ../model/dce-manager.cc:281
#4 0x000006d67d1b90 in ns3::TaskManager::Trampoline (context=0x633bd0) at ../model/task-manager.cc:267
#5 0x000006d67d1a87 in ns3::PthreadFiberManager::Run (arg=0x634040) at ../model/pthread-fiber-manager.cc:402
#6 0x000006d69ebe26cb in start_thread (arg=0x7fffffff7c00) at pthread_create.c:301
#7 0x000006d69ebe02d in clone () at ../sysdeps/unix/sysv/linux/x86_64/clone.S
```

```c
(gdb) info thread
Id Target Id Frame
* 2 Thread 0x7fffffff7c00 (LWP 15233) "dce-sleep" dce_sleep (seconds=10) at ../model/dce.cc:226
```

```c
1 Thread 0x7fffffff660040 (LWP 15230) "dce-sleep" pthread_cond_wait@GLIBC_2.3.2 ()
```
We can notice that `sleep` call `dce_sleep` which call `Wait`, this `Wait` method is from the class `TaskManager`. `TaskManager` is a major class of DCE and we will detail it below. Basically `Wait` schedules and event in `ns-3` event queue (in order to be woken up after sleep time) and give the control to another `Task`. Now we can put a breakpoint in `ns3::DefaultSimulatorImpl::ProcessOneEvent` and see the time advance up to 10s:

```
gdb) b ns3::DefaultSimulatorImpl::ProcessOneEvent
Breakpoint 2 at 0x7fffff7619207: file ../src/core/model/default-simulator-impl.cc, line 131.
gdb) c
Continuing.
[Switching to Thread 0x7fffff6600740 (LWP 3942)]
Breakpoint 2, ns3::DefaultSimulatorImpl::ProcessOneEvent (this=0x6308e0) at ../src/core/model/default-simulator-impl.cc:131
warning: Source file is more recent than executable.
131   Scheduler::Event next = m_events->RemoveNext ();
(gdb) n
133   NS_ASSERT (next.key.m_ts >= m_currentTs);
(gdb) n
134   m_unscheduledEvents--;
(gdb) n
136   NS_LOG_LOGIC ("handle " << next.key.m_ts);
(gdb) n
137   m_currentTs = next.key.m_ts;
(gdb) n
138   m_currentContext = next.key.m_context;
(gdb) p m_currentTs
$1 = 10000000000
(gdb)
```

This next event will wake the thread 2 will therefore complete the `sleep` of our scenario.

In summary we saw briefly that DCE uses the events of `ns-3` to schedule the execution between different tasks.

5.3. Follow a very simple example
Below are the list of the tested applications with DCE.

- **CCNx**
- **Quagga**
- **iperf**
- **ping/ping6**
- **ip (iproute2 package)**
- **umip (Mobilt IPv6 daemon)**
- **Linux kernel (from 2.6.36 to 3.14 version)**
- **FreeBSD kernel (10.0.0 version)**
- **thttpd**
- **torrent**

### 6.1 CCNx

**CCNx** is an open source implementation of *Content Centric Networking*. All the C written executables are supported and none of the Java ones. The versions tested are those between 0.4.0 and 0.6.1 included.

For more detail document, see dce-ccnx.

### 6.2 Quagga

**Quagga** is a routing software suite, providing implementations of OSPFv2, OSPFv3, RIP v1 and v2, RIPng and BGP-4 for Unix platforms, particularly FreeBSD, Linux, Solaris and NetBSD. [More information.](#)

### 6.3 iperf

iperf from the following archive [http://walami.googlecode.com/files/iperf-2.0.5.tar.gz](http://walami.googlecode.com/files/iperf-2.0.5.tar.gz) as been tested. It is the exception that proves the rule. That is to say that this particular example requires a change in its code. In the source file named
Thread.c at line 412 in the function named thread_rest you must add a sleep(1) in order to help DCE to break the infinite loop.

6.4 ping/ping6

Ping from the following archive http://www.skbuff.net/iputils/iputils-s20101006.tar.bz2 is supported.

6.5 ip (iproute2 package)

6.6 umip (Mobilt IPv6 daemon)

The umip (Usagi-Patched Mobile IPv6 stack) support on DCE enables the users to reuse routing protocol implementations of Mobile IPv6. UMIP now supports Mobile IPv6 (RFC3775), Network Mobility (RFC3963), Proxy Mobile IPv6 (RFC5213), etc, and can be used these protocols implementation as models of network simulation.

For more information, see the latest support document.

6.7 Linux kernel (from 2.6.36 to 3.14 version)

Linux kernel support is built with a separate ‘dce-linux’ module, available on github. Many protocols implemented in kernel space such as TCP, IPv4/IPv6, Mobile IPv6, Multipath-TCP, SCTP, DCCP, etc, are available with ns-3.

6.8 FreeBSD kernel (10.0.0 version)

FreeBSD kernel support is based on Linux kernel module of DCE. A few protocols implemented in kernel space such as TCP, IPv4, etc, are available with ns-3.

6.9 thttpd

(TBA)

6.10 torrent

(TBA)
The creator of DCE is Mathieu Lacage.
The current maintainers and developers are Hajime Tazaki and Frédéric Urbani.

7.1 Contacts

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