

# 임베디드 소프트웨어 통합개발환경 : Esto

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임베디드S/W연구단

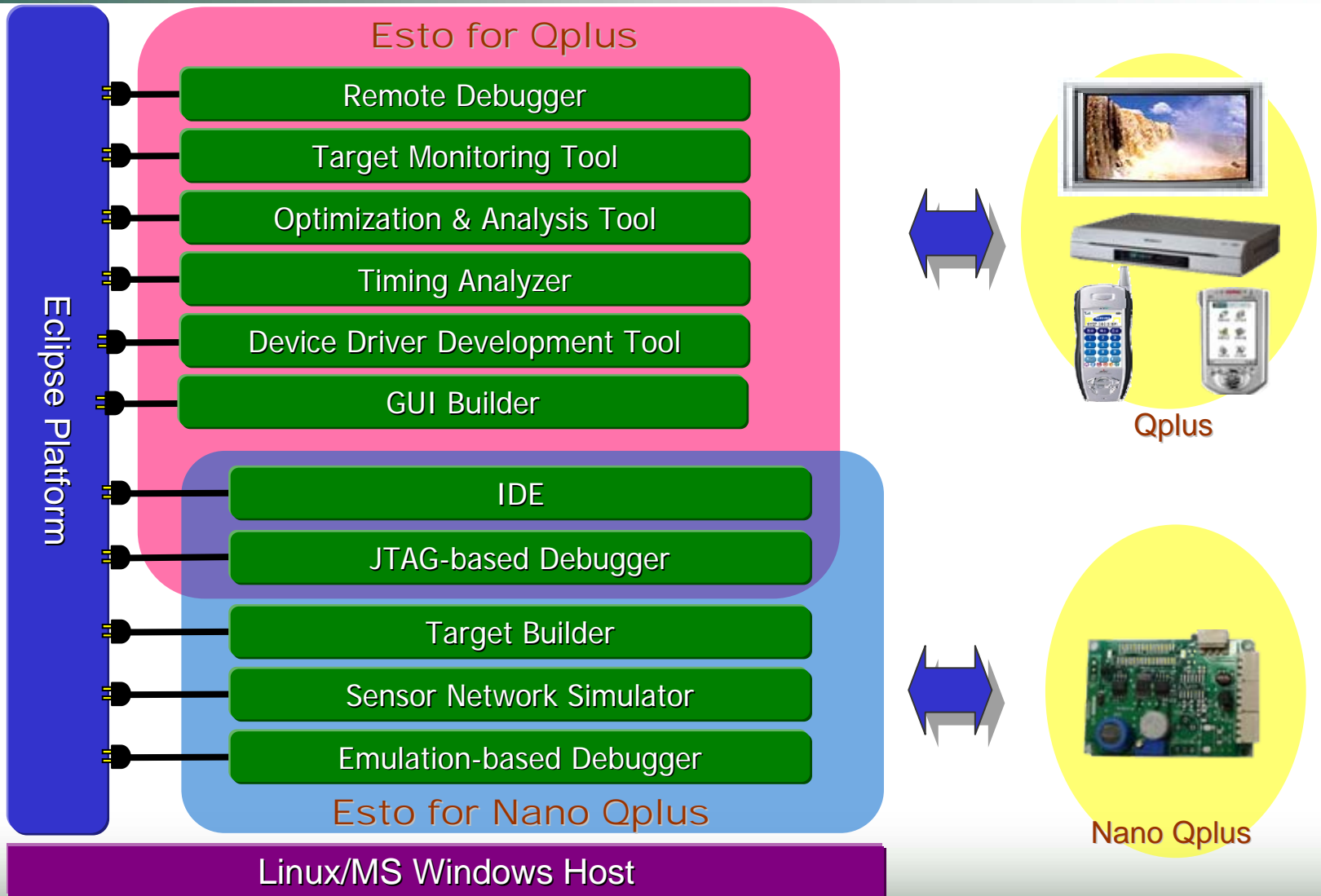
**ETRI** 한국전자통신연구원  
Electronics and Telecommunications  
Research Institute

# Contents



- ❖ Introduction to Esto, Qplus and Nano Qplus
- ❖ Esto for Qplus
- ❖ Esto for Nano Qplus (Nano Esto)
- ❖ Optimization and Analysis Tool
- ❖ Sensor Network Simulator
- ❖ Demonstration

# Esto



# Esto Features



- ❖ Accelerate Developer Productivity of Qplus and Nano Qplus based Embedded Software
- ❖ Based on Eclipse
- ❖ Esto for Qplus
  - Target
    - X86, ARM, Xscale, MIPS, PowerPC
  - Project based source editing, cross compilation, remote execution
  - Remote debugging for application and kernel module
  - Non-stop debugging
  - JTAG-based firmware debugging
  - Monitoring various target resources (CPU, memory, etc.)
  - Power, performance analysis and source code optimization
  - Integrated and seamless analysis on schedulability and WCET (Worst Case Execution Time)
- ❖ Esto for Nano Qplus (Nano Esto)
  - Target
    - AVR
  - Project based source editing, cross compilation, remote execution
  - Automatic loading of executable image to target system
  - JTAG-based sensor node debugging
  - Emulator-based debugging
  - GUI-based sensor network simulation
  - Simulation-based power analysis for sensor network
  - Fast and convenient kernel configuration and build

## ❖ Kernel Features

- Real-Time
  - Preemptible kernel
  - POSIX high resolution timer
- Power Management
  - ACPI
  - Support safe turn off functionality
- Fast Boot
  - PRESET LPJ (Loops Per Jiffy)  
Save 350 msec on EPIA-M board
- TV OUT kernel frame buffer

## ❖ Other Features

- TinyX
- Matchbox window manager
- Gtk-2.6
- GPE based application management environment
- Web browser : minimo firefox-1.0.6
- Media player : mplayer-1.0

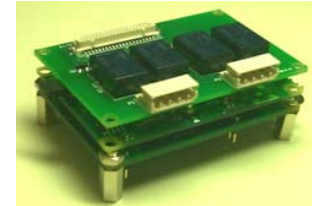
## ❖ Target Builder

- Embedded system configuration toolkit
- Easy build up target root file system
- Kconfig based integrated configuration system
  - Linux kernel 2.6.x
  - Automated dependency checking
- RPM based packaging system
- Library optimization
- Fine-grain control of system
  - File-list, compile options, etc.
- Support various root filesystem types
  - ext2, ext3, ramdisk image, jffs2, etc.
- Support various deployment methods
  - CD installer, USB memory stick installer, serial installer, NFS, etc.
- Based on Eclipse platform
- Licensed by GPL
- Include CELF patches currently 2.6.9

# Nano Qplus



- ❖ Small-sized, Distributed, Real-time, and Smart OS
- ❖ For Sensor Networks under Ubiquitous Environment
  - E.g., medical services, environmental systems, disaster prevention, digital home, national defense systems, etc.

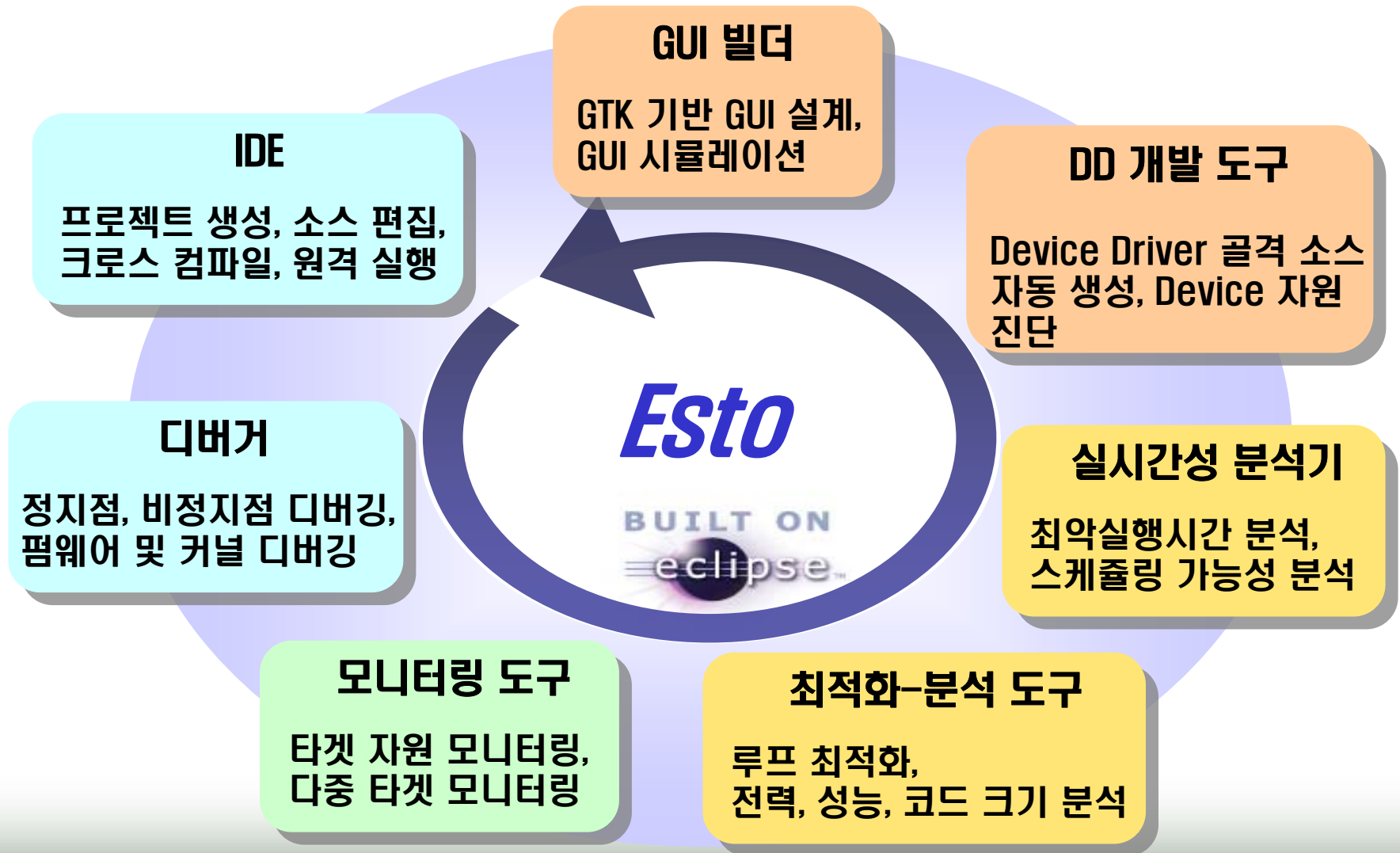


- ❖ Main Features

- Reconfigurable, scalable OS
  - Can be optimized for various sensors and actuators
  - Supports better S/W architecture than TinyOS of UC Berkeley
- Various scheduling policies
  - FIFO, Preemption, LEDF, etc.
- Various wireless communications
  - RF, ZigBee, Bluetooth, etc.
- Same API sets as Qplus



# Esto for Qplus

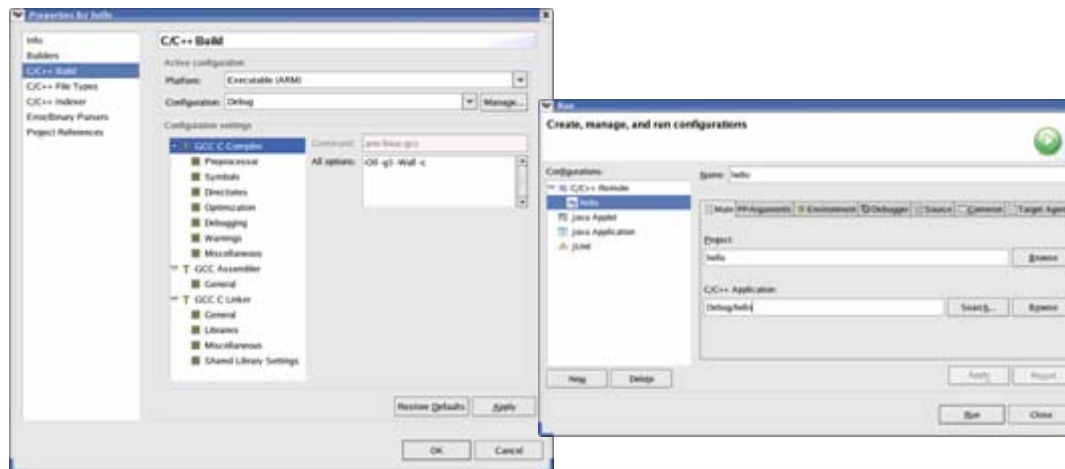


## ❖ Project Management

- Creation, configuration, and building
- Makefile management
- Qplus package import/export

## ❖ Development

- Source code editing facilities
  - Syntax highlighting, automatic formatting, class browsing, etc.



Project Build & Remote Execution Configuration



# Debugger

## ❖ Remote Debugger

- Remote debugging starts with just one button click
- Nonstop-debugging with tracepoint and replay
  - For time-sensitive applications

## ❖ JTAG-based Debugger

- A cost-effective way to debug applications on a target system
  - Needs only a cheap JTAG adaptor
- Supports full C source level debugging
- Supports both breakpoint & tracepoint

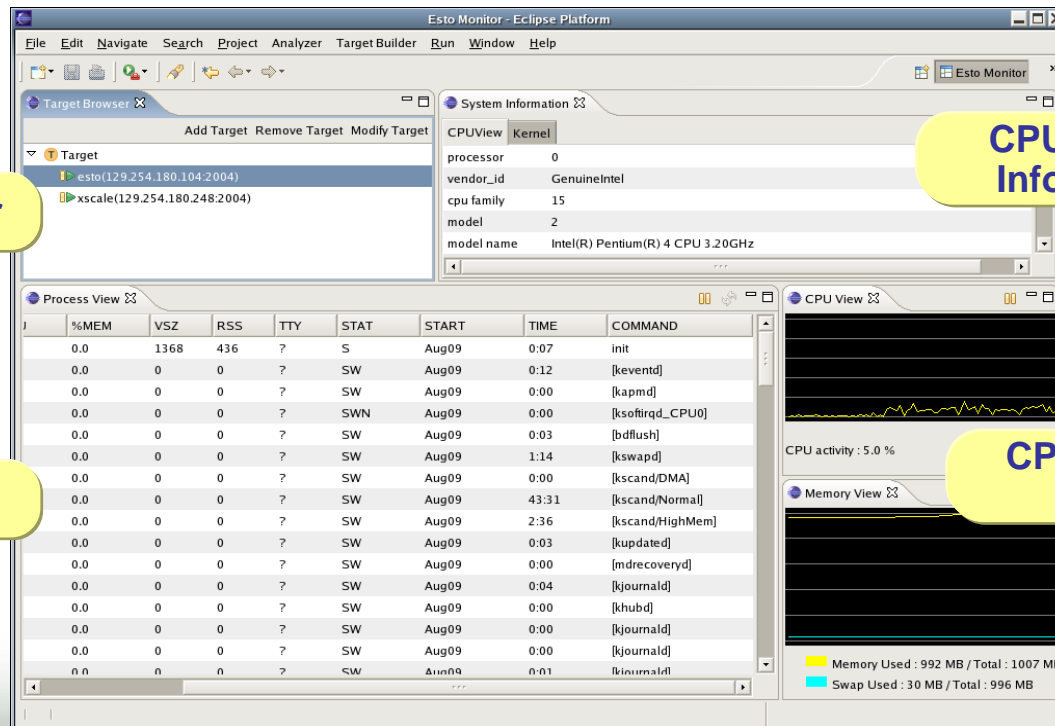
# Snapshot of Debugger

The screenshot displays the Eclipse IDE with the GDB debugger. The interface is annotated with yellow callouts and red dashed boxes:

- Call stack view:** Located at the top left, showing the current thread (Thread [1]) and the current function (main() at ../main.cpp:93).
- Variables view:** Located at the top right, displaying a list of variables including pointers to shape classes (p1, p2, p3), a vector, and a normal\_iterator.
- Source view:** Located in the center, showing the source code of the main() function. The current line of execution is highlighted.
- Source outline:** Located on the right side, showing a tree view of the source files and classes, including 'shape.h' and 'myshape'.
- Register view:** Located in the bottom right, showing the current state of CPU registers (eax, ecx, edx, etc.).
- Console view:** Located at the bottom, showing the output of the program.

# Target Monitoring Tool

- ❖ Concurrent multiple-target monitoring
- ❖ Various target resource monitoring
  - CPU, memory, process list, process memory map, kernel module, etc.
- ❖ GUI based kernel event trace
- ❖ Remote tracing of system call and library function



The screenshot displays the Esto Monitor Eclipse Platform interface. The 'System Information' view shows CPU and kernel details. The 'Process View' shows a list of running processes. The 'CPU View' and 'Memory View' show real-time usage graphs and statistics.

J	%MEM	VSZ	RSS	TTY	STAT	START	TIME	COMMAND
0.0	1368	436	?	?	S	Aug09	0:07	init
0.0	0	0	?	?	SW	Aug09	0:12	[keventd]
0.0	0	0	?	?	SW	Aug09	0:00	[kapmd]
0.0	0	0	?	?	SWN	Aug09	0:00	[ksftirqd_CPU0]
0.0	0	0	?	?	SW	Aug09	0:03	[bdflush]
0.0	0	0	?	?	SW	Aug09	1:14	[kswapd]
0.0	0	0	?	?	SW	Aug09	0:00	[kscand/DMA]
0.0	0	0	?	?	SW	Aug09	43:31	[kscand/Normal]
0.0	0	0	?	?	SW	Aug09	2:36	[kscand/HighMem]
0.0	0	0	?	?	SW	Aug09	0:03	[kupdated]
0.0	0	0	?	?	SW	Aug09	0:00	[mdrecoveryd]
0.0	0	0	?	?	SW	Aug09	0:04	[kjournald]
0.0	0	0	?	?	SW	Aug09	0:00	[khubd]
0.0	0	0	?	?	SW	Aug09	0:00	[kjournald]
0.0	0	0	?	?	SW	Aug09	0:00	[kjournald]
0.0	0	0	?	?	SW	Aug09	0:01	[kjournald]

CPU activity : 5.0 %

Memory Used : 992 MB / Total : 1007 MB  
Swap Used : 30 MB / Total : 996 MB

CPU/Kernel Information

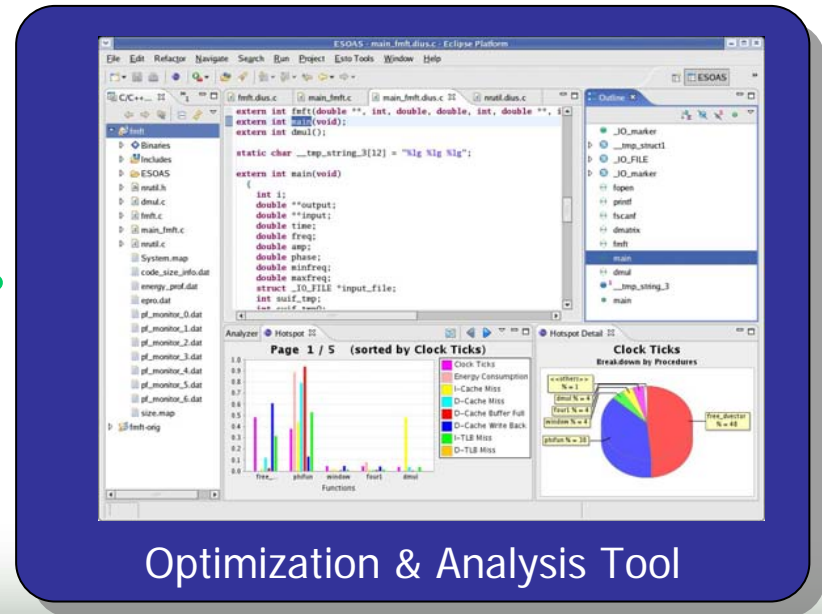
Target Browser

Process List

CPU/Memory Usage

# Optimization and Analysis Tool

- ❖ Optimizing Application
  - By using loop transformation such as loop distribution, loop interchange, loop unrolling, and scalarization
- ❖ Analyzing Power of Embedded Application
  - Together with performance and code size
- ❖ GUI-Based Integration of Optimizing and Analyzing



# Timing Analyzer



## ❖ Static timing analyzer for C/C++ based real-time application

### ■ Analyzes WCET (Worst-Case Execution Time)

- Considering XScale micro-architecture's characteristics such as pipeline & cache.
- WCET analysis for OS components, such as a scheduler and interrupt service routines, based kernel source code

### ■ Analyzes Schedulability based on RMA (Rate Monotonic Analysis)

TMO	Type	Name	Period	WCET	Blocking	Jitter	Deadline	Response Time	Schedulability
OpticalSensorTMO	SpM	SenseObjectSpM	500000	2309	2309	2000	30000	18274	schedulable
OpticalSensorTMO	SvM	CheckDetectionSvM	450000	4109	4109	0	50000	8228	schedulable
DoorTMO2	SpM	SenseDoorSpM1	500000	2409	2409	2000	15000	20785	unschedulable
DoorTMO2	SpM	SenseDoorSpM2	500000	2409	2409	2000	15000	23196	unschedulable
DoorTMO2	SpM	MoveDoorSpM	450000	7533	7533	2000	400000	21187	schedulable

Analyzed WCET

Final results of  
schedulability analysis

## ❖ 특징

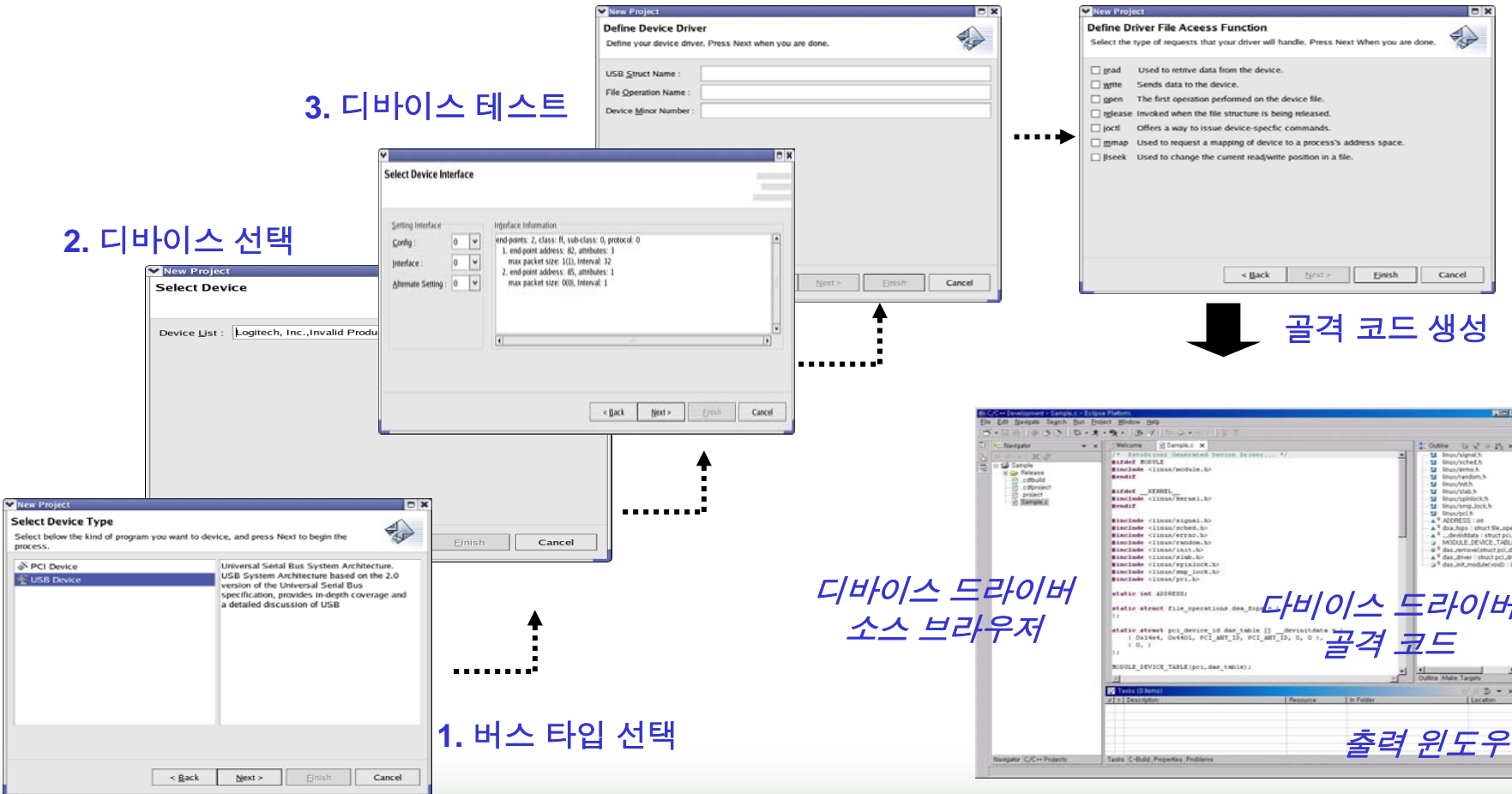
- 드라이버 프로젝트 위저드
  - 디바이스 드라이버의 골격 코드 생성을 안내해줌
  - 드라이버 타입(문자, 블록, 네트워크)과 디바이스 타입(PCI, USB, IEEE1394, 디바이스 없는 경우)을 고려한 골격 코드 생성
- 디바이스 테스트 위저드
  - 즉시 하드웨어에 접근하고 진단 가능
  - PCI, USB, IEEE1394 디바이스 리소스 테스트 제공
- 원격 개발 지원
  - 타겟에 디바이스 드라이버 다운로드
  - 디바이스 드라이버를 타겟 커널에 삽입/제거 가능
  - 커널 메시지 로깅 뷰어
  - 커널 API 원격 실행기

# 디바이스 드라이버 개발 도구



- 3. 디바이스 테스트
- 4. 드라이버의 기본 정보 정의
- 5. 디바이스 드라이버의 파일 함수 선택

## 2. 디바이스 선택



디바이스 드라이버 소스 브라우저

디바이스 드라이버 골격 코드

출력 윈도우

# GUI 빌더 (gDesigner)

디자인 창

위젯 삽입 기능

위젯 속성 편집 기능

시뮬레이션 화면

Hardware button 이벤트 테스트



Desktop PC / Notebook PC



# Esto for Nano Qplus (Nano Esto)



# Target Builder for Nano Qplus

## ❖ Unified Configuration System

- Configures kernel, packages and target specific options altogether
- Dependencies are checked automatically

## ❖ Easy and Fast Kernel Build System

- Just load provided pre-configurations for a certain BSP
- Point & Click selection of each module with user friendly GUI

The screenshot shows the Target Builder Main window with the following components:

- Project Tree:** Located on the left side of the window, showing a hierarchical view of the project files and folders.
- Unified Configuration Tree:** The central pane displays a tree of configuration options for the Nano Q+ system, including board selection, menu options, and various hardware modules like UART, print, scanf, and actuation.
- Help, File List:** A pane on the right provides detailed help for the selected configuration option, including its prompt, type, size, and value.
- Dependency:** A section below the help pane shows the dependency of the selected option on other configuration options.
- Symbol:** A table at the bottom right lists the symbols and their values for the current configuration.
- Build Log:** A console window at the bottom of the interface displays the build process logs.

Symbol	Prompt	Value
ETRI_SSN	ETRI_SSN	y
MINI_SSN	MINI_SSN	n
UART_M	Enable UART module	y

## ❖ C source editor

- Offers highlighting syntax, auto indentation, and browsing facilities for showing variables and functions

## ❖ Project Manager

- Provides project creation, configuration and building

## ❖ Executable Image Downloader (Fusing Tool)

- Downloads and runs applications on a target system with just a click

## ❖ Rapid prototyper

- Creates skeleton code based on user's kernel module selection
- Users do not have to develop applications from scratch

# Debugger

## ❖ Emulator based approach

- checks stability before downloading an executable image
- Supports debugging without a target system

## ❖ JTAG based approach

- A cost-effective way to debug applications on a target system
  - Needs only a cheap JTAG adaptor
- Supports full C source level debugging

# Snapshot of Debugger

The screenshot displays the Eclipse Platform debugger interface for a Nano Application named 'timer\_blink'. The main window shows the source code of 'timer\_blink.c' with a blue dashed box highlighting the 'main' function. A red dashed box highlights a break point set at line 345. The 'Call Stack' window on the left shows the current execution context. The 'Registers' window on the right lists registers r27 through r31, SREG, and SP. The 'Outline' window on the bottom right shows the project's file structure. Red arrows point to the 'Variables', 'Memory', and 'Registers' tabs. A blue arrow points to the 'Source Outline' window. A red dashed box highlights a break point in the source code.

**Variables**

**Memory**

**Registers**

**Call Stack**

**Break point**

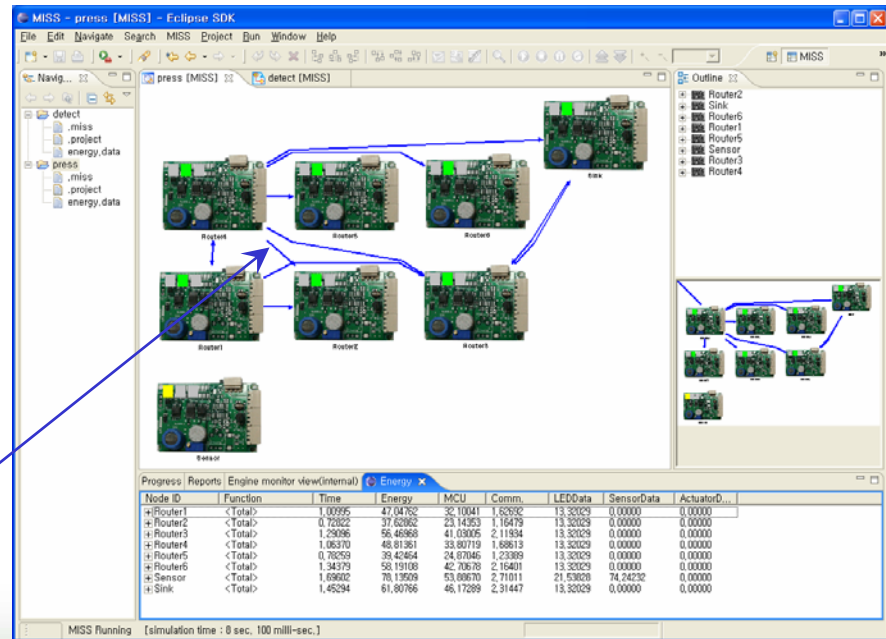
**Source Outline**

```
1-0-0-
1 // while (i<10) {
2     LED0_BLINKING();
3     halWait(5000);
4     LED1_BLINKING();
5     halWait(5000);
6     LED2_BLINKING();
7     halWait(5000);
8     i++;
9 }
10 puts("end blink.\n");
11
12 return NULL;
13 }
14
15 /* receive task */
16 void rf_rcv_data(MACADDR srcAddr, INT8 nbyte, BYTE *data)
17 {
18     // handling received message
19 #ifndef TX_NODE
20     SET_LED_BINARY(data[0]);
21     //SET_LED_MASK(1 << ((data & 0x03)));
22 #endif /* !TX_NODE */
23 }
24
25 /* send task */
26 void *rf_send_data(void *arg)
27 {
```

# Sensor Network Simulator

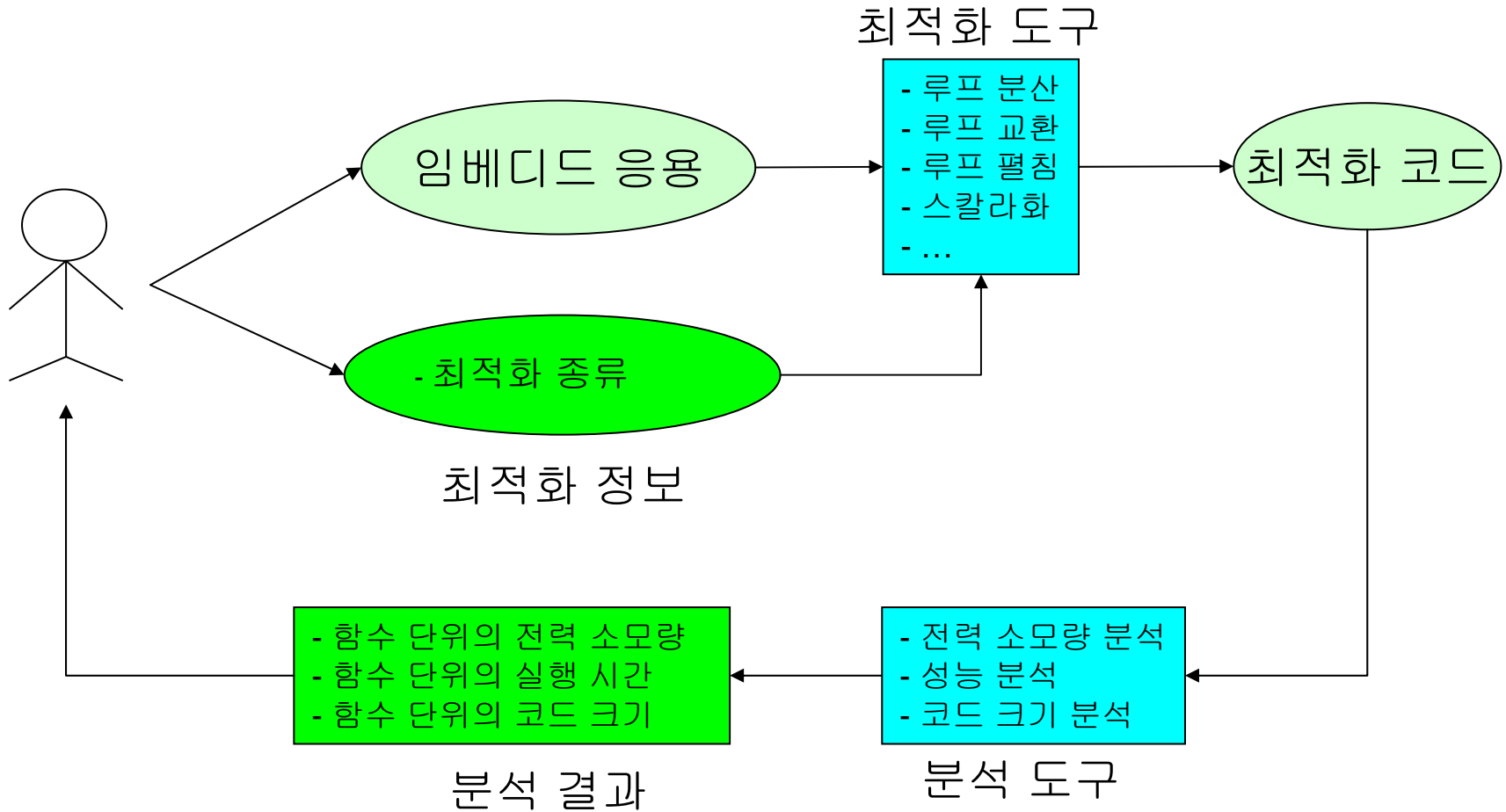
- ❖ Scalable network environment simulation
  - Verifies hardware/software design of sensor network
  - Provides a controlled environment for evaluating design alternatives
  - Tests stability of certain network topology
- ❖ Precise target sensor node simulation
  - Simulates executable image, which contains machine instructions of ATmega128 core in instruction level
- ❖ Accurate power consumption estimation
  - Estimates power consumption of sensor network based on instruction-level power modeling of Atmega128

**Routing path between two sensor nodes**



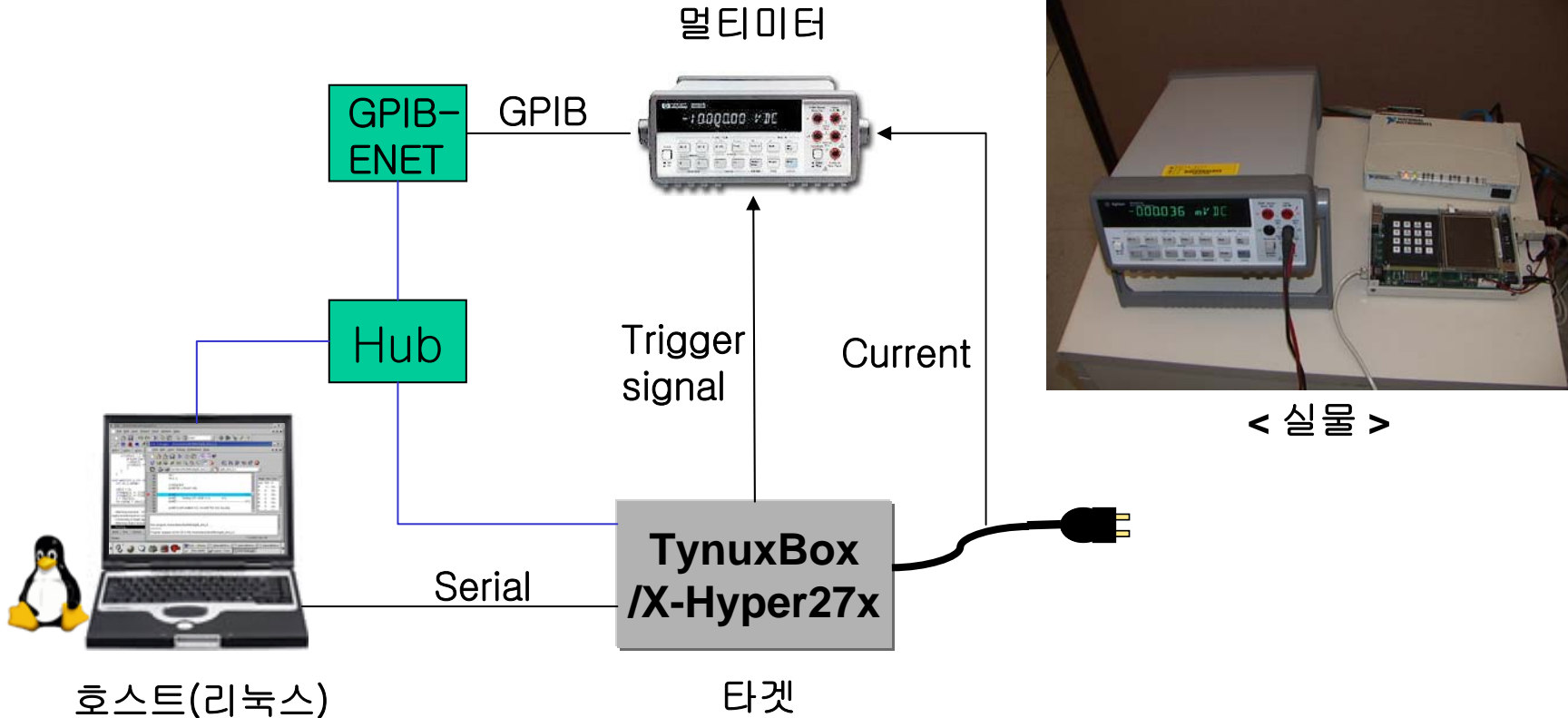
# - 최적화- 분석 도구

# 최적화-분석 도구 개념도

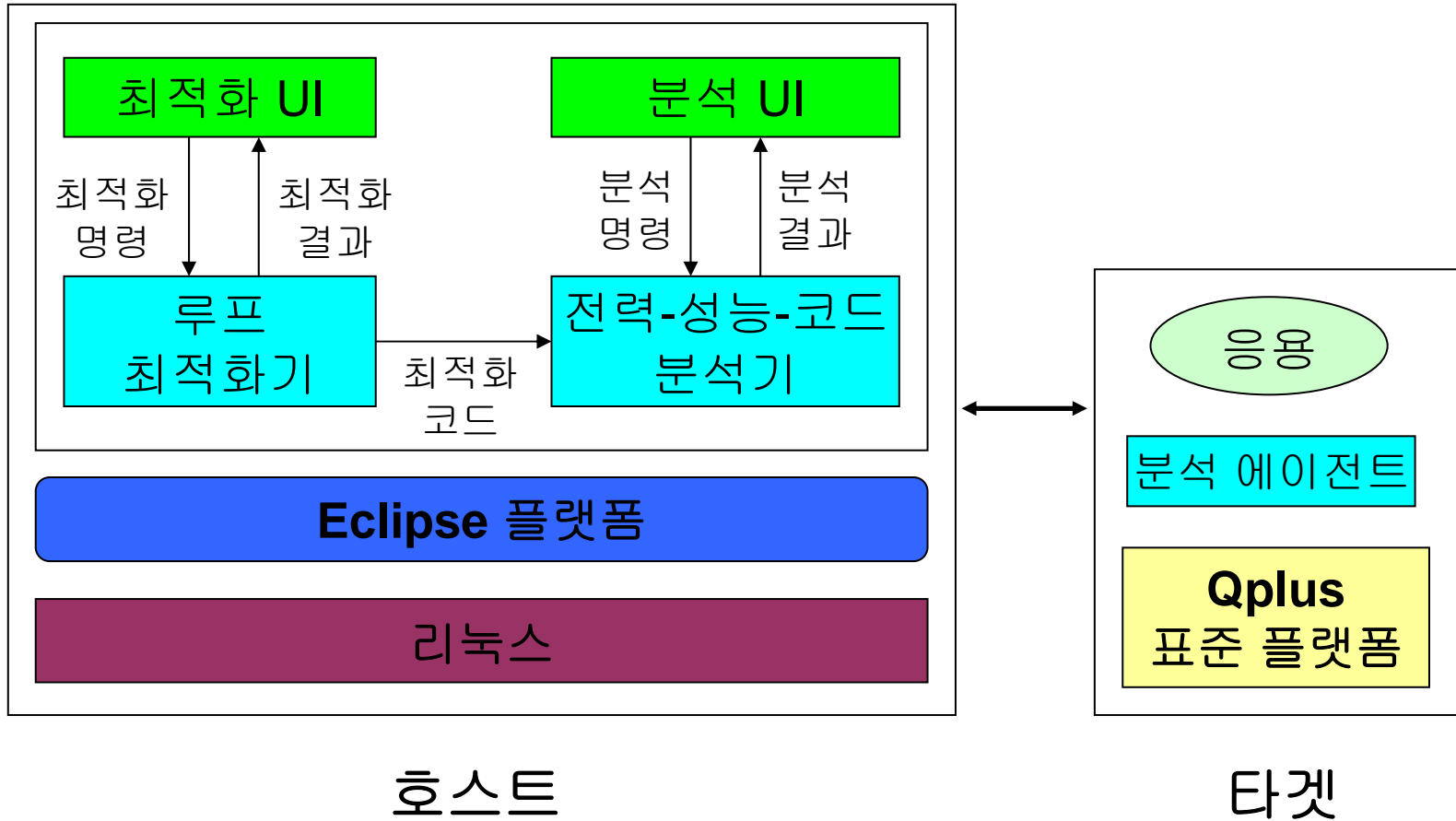




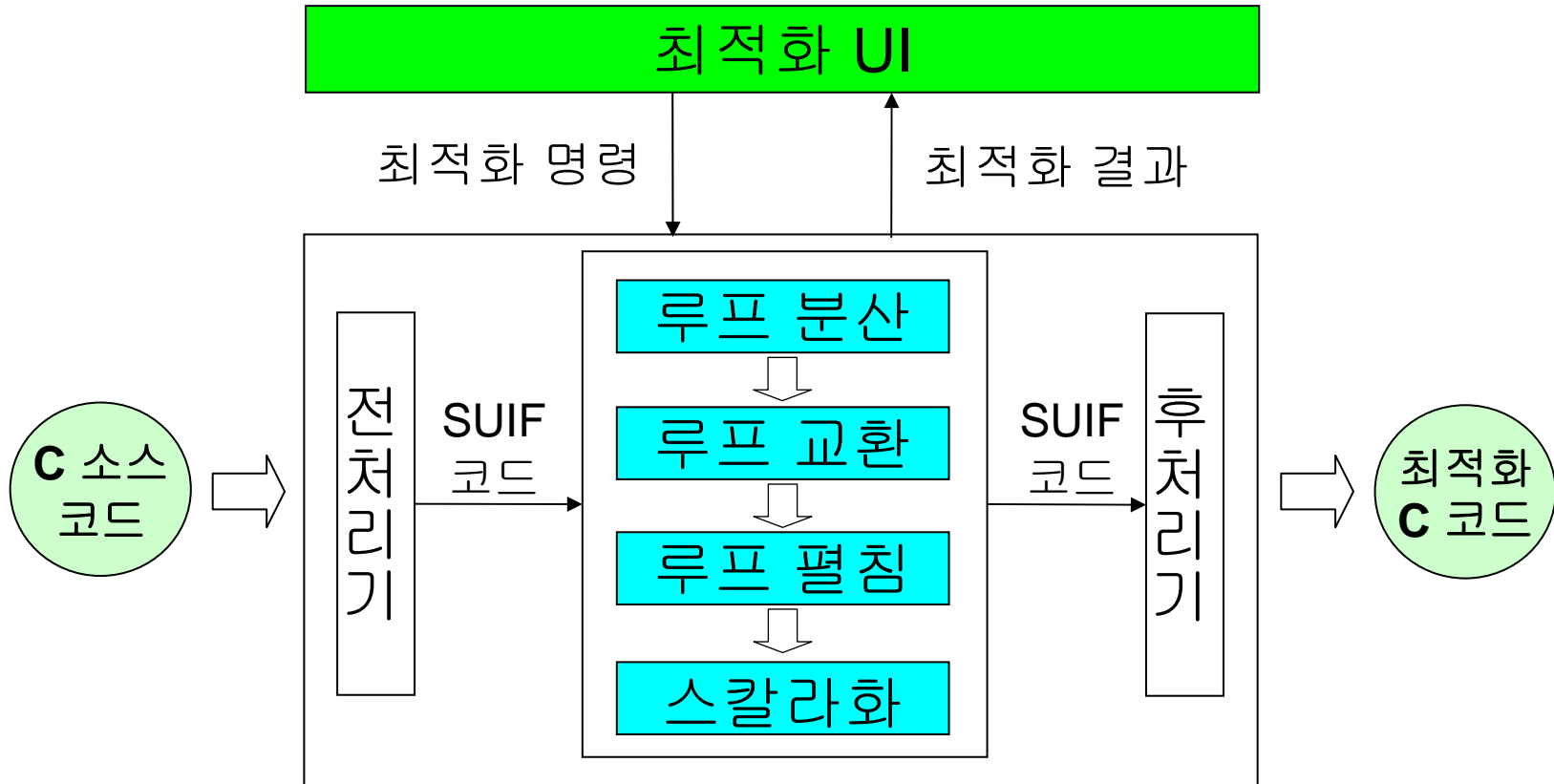
# 최적화-분석 도구 설치 환경



# 최적화-분석 도구 구조



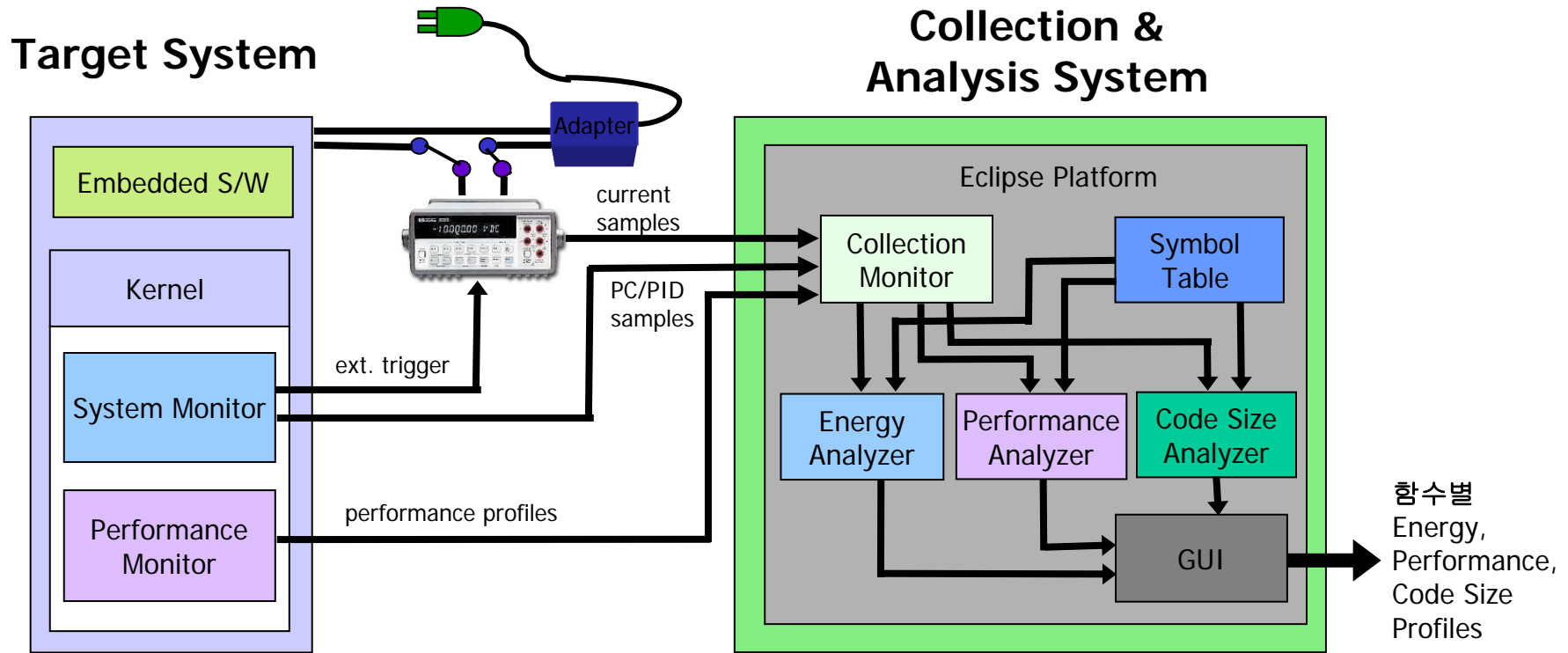
# 최적화 도구 구조



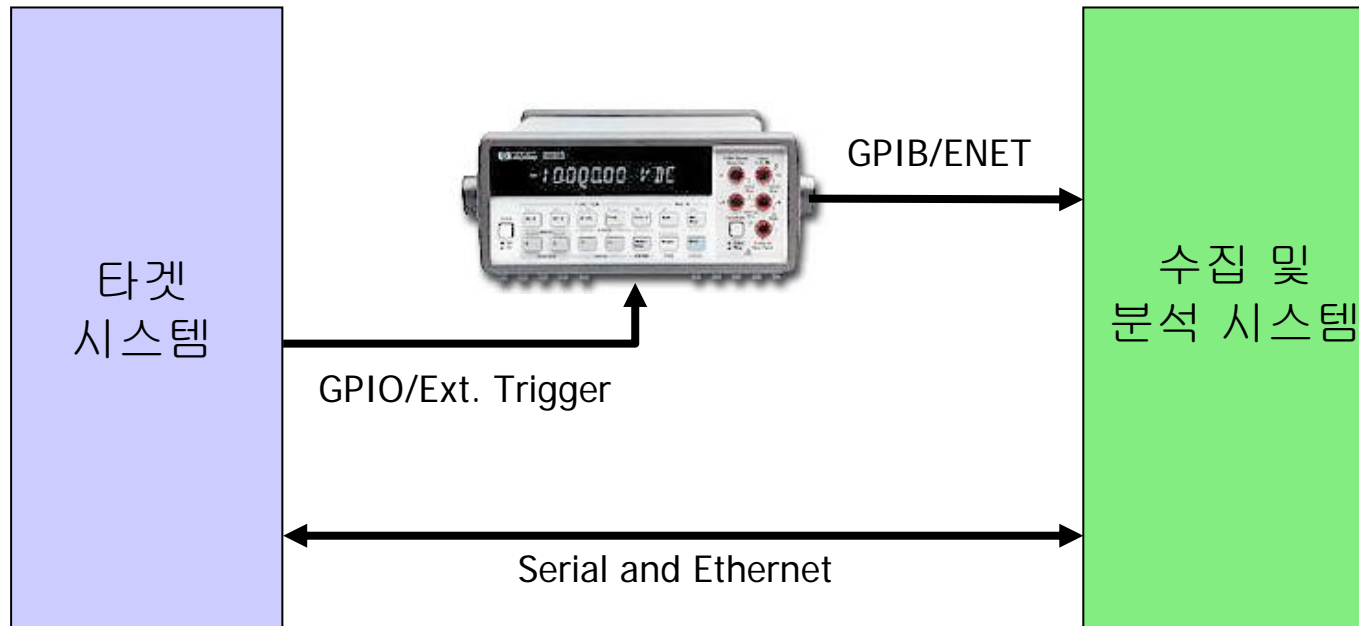
❖ UI : Eclipse 기반

❖ 엔진 : Stanford 대학교에서 개발한 SUIF 컴파일러 시스템 기반

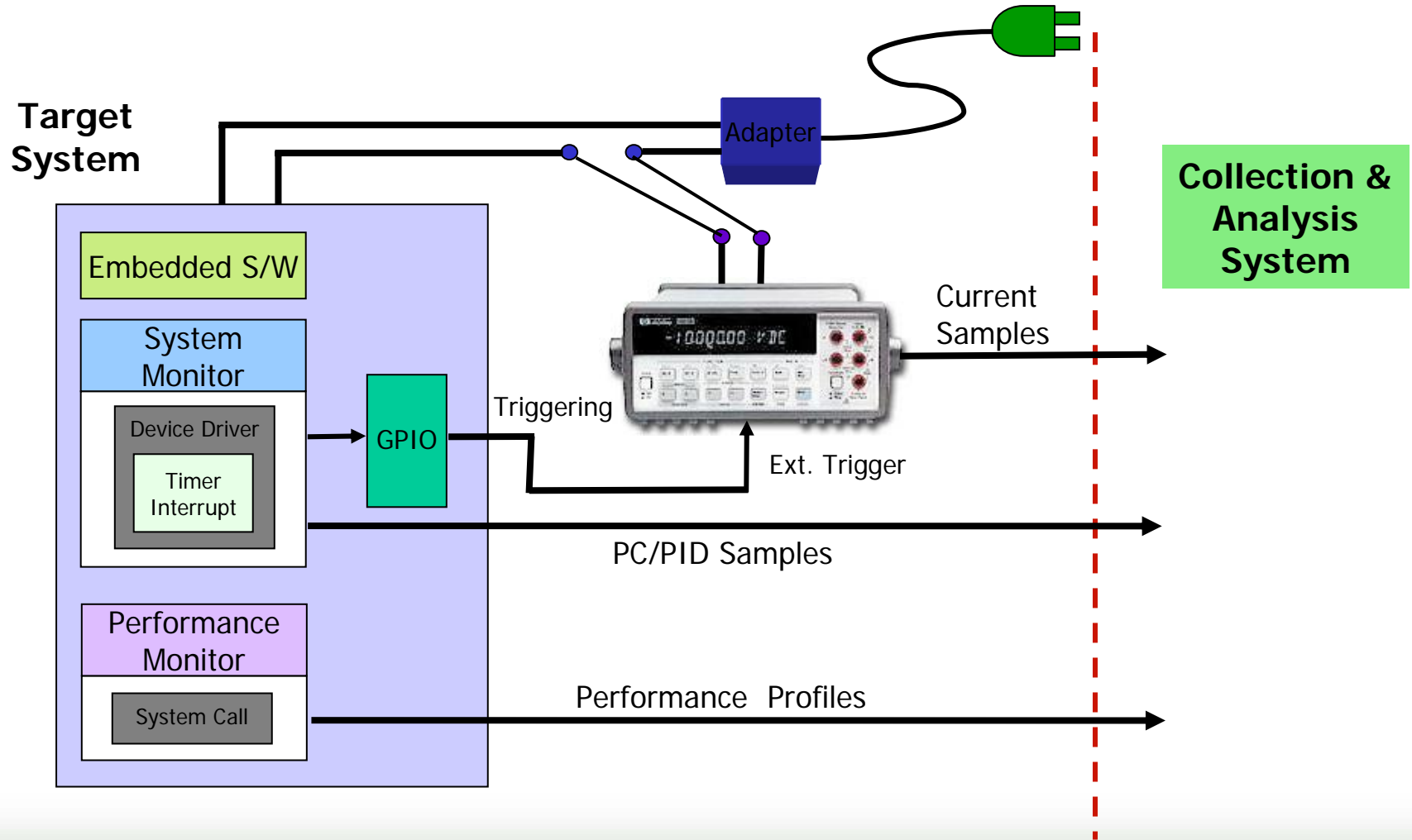
# 분석 도구 구조



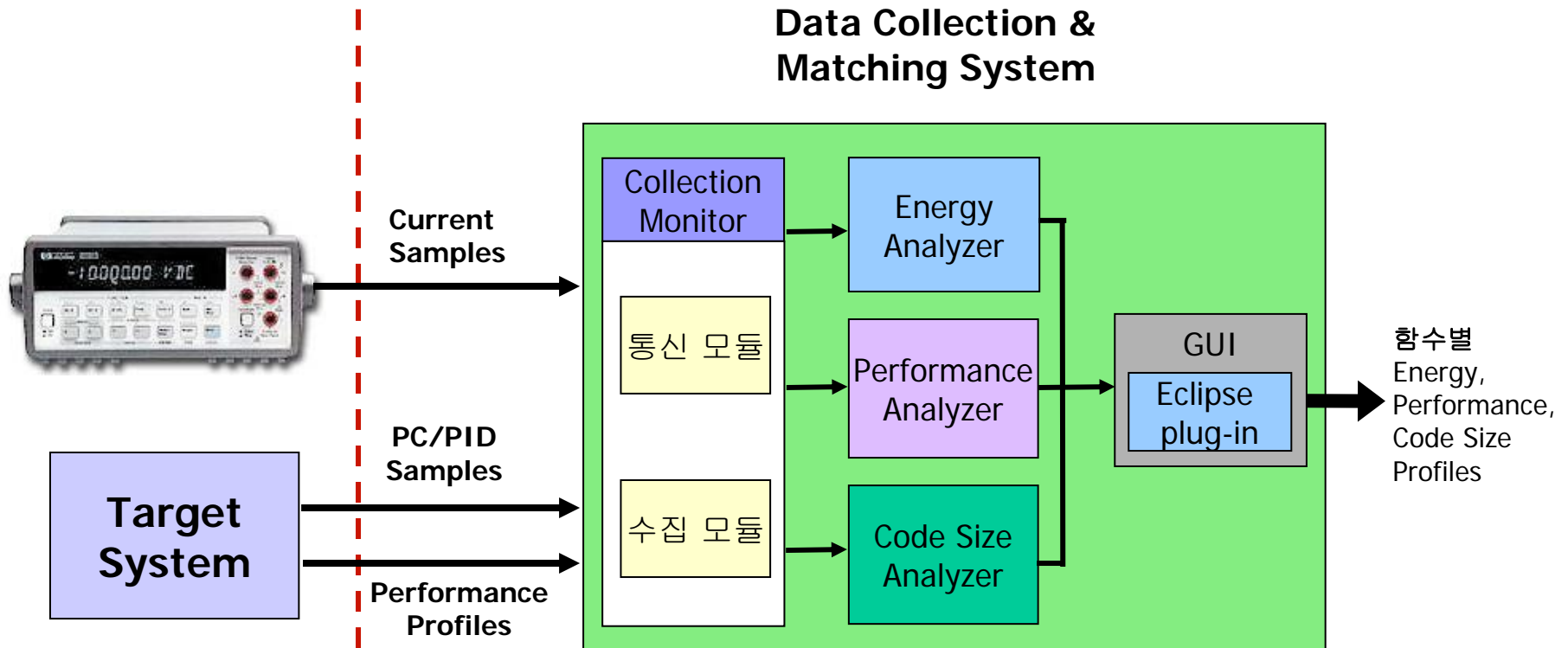
# 전력 분석 도구 인터페이스



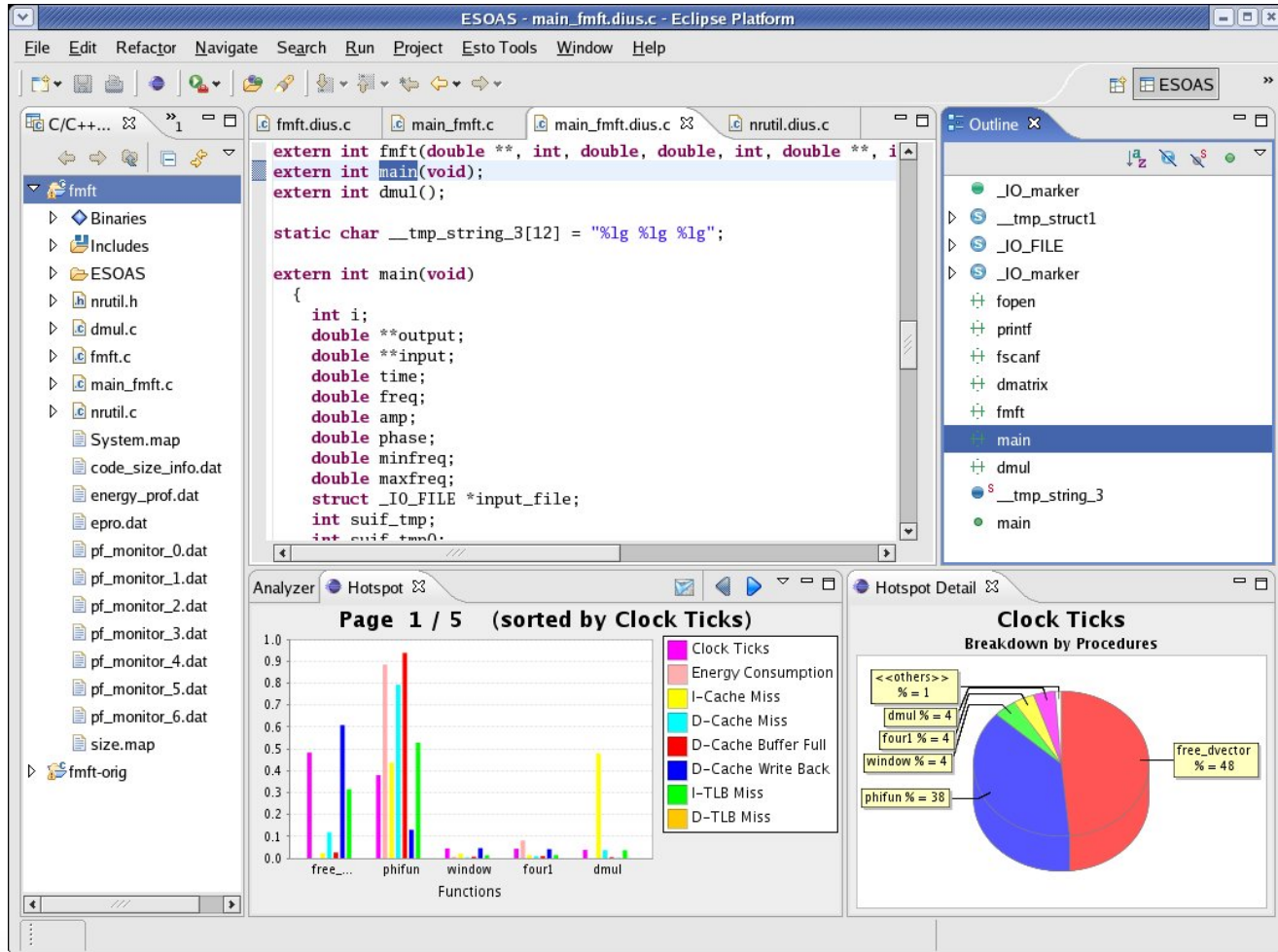
# Target System



# Collection & Analysis System



# 최적화-분석 도구 실행 화면



ESOAS - main\_fmft.dius.c - Eclipse Platform

File Edit Refactor Navigate Search Run Project Esto Tools Window Help

C/C++... » 1

fmft.dius.c main\_fmft.c main\_fmft.dius.c nrtutil.dius.c

```
extern int fmft(double **, int, double, double, int, double **, i
extern int main(void);
extern int dmul();

static char __tmp_string_3[12] = "%lg %lg %lg";

extern int main(void)
{
    int i;
    double **output;
    double **input;
    double time;
    double freq;
    double amp;
    double phase;
    double minfreq;
    double maxfreq;
    struct _IO_FILE *input_file;
    int suif_tmp;
    int suif_tmp0;
```

Outline

- \_IO\_marker
- ▷ S \_\_tmp\_struct1
- ▷ S \_IO\_FILE
- ▷ S \_IO\_marker
- + fopen
- + printf
- + fscanf
- + dmatrix
- + fmft
- + main
- + dmul
- S \_\_tmp\_string\_3
- main

Analyzer Hotspot

Page 1 / 5 (sorted by Clock Ticks)

Legend:

- Clock Ticks
- Energy Consumption
- I-Cache Miss
- D-Cache Miss
- D-Cache Buffer Full
- D-Cache Write Back
- I-TLB Miss
- D-TLB Miss

Functions: free..., phifun, window, four1, dmul

Hotspot Detail

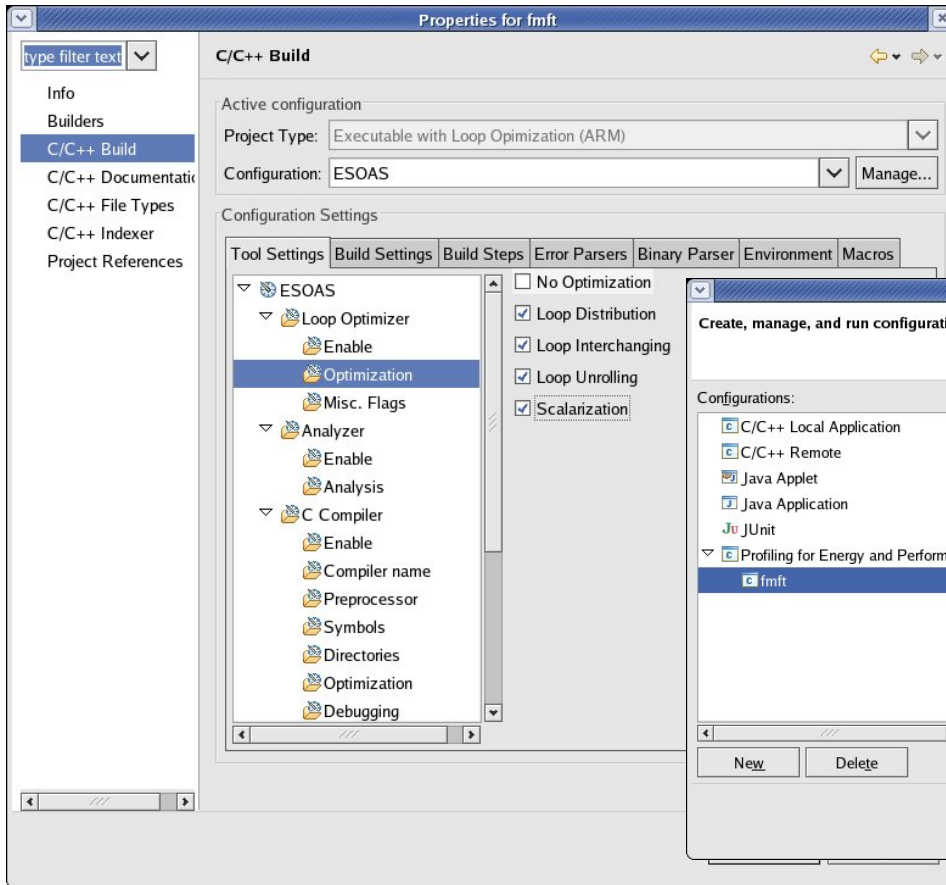
Clock Ticks Breakdown by Procedures

- <<others>> % = 1
- dmul % = 4
- four1 % = 4
- window % = 4
- phifun % = 38
- free\_dvector % = 48

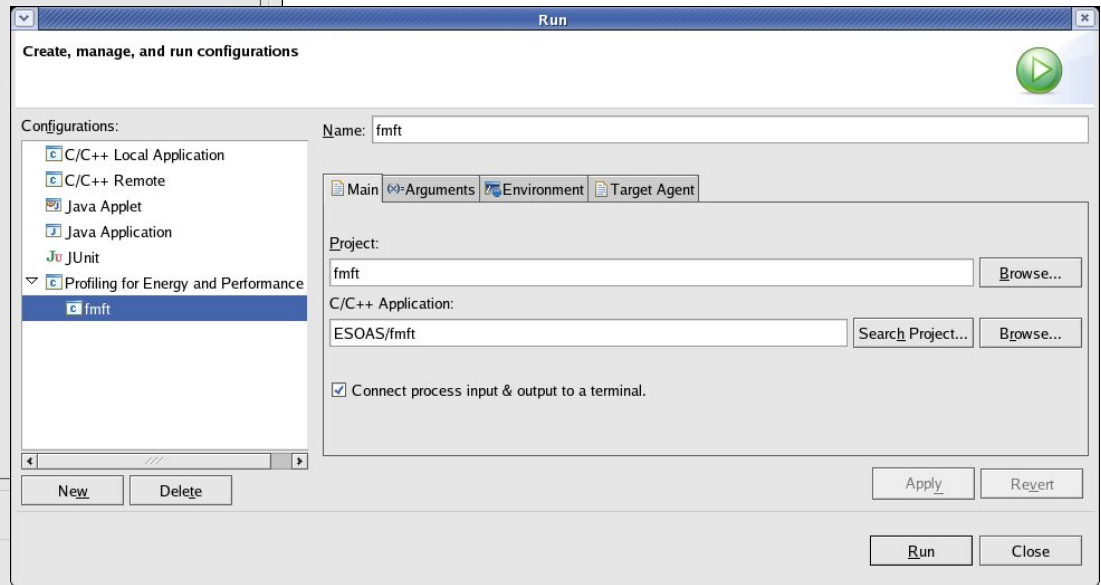


# 빌드 & 실행 설정 UI

## < 빌드 설정 >

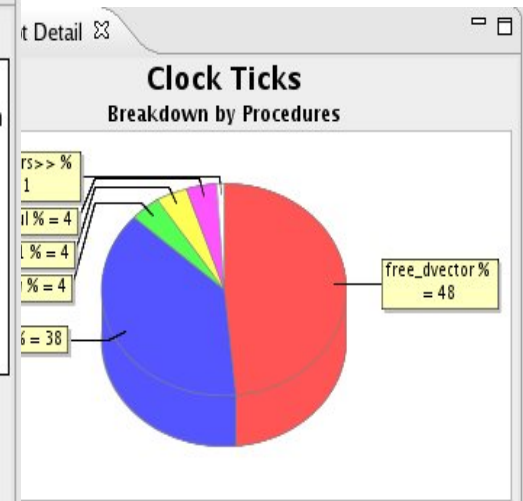
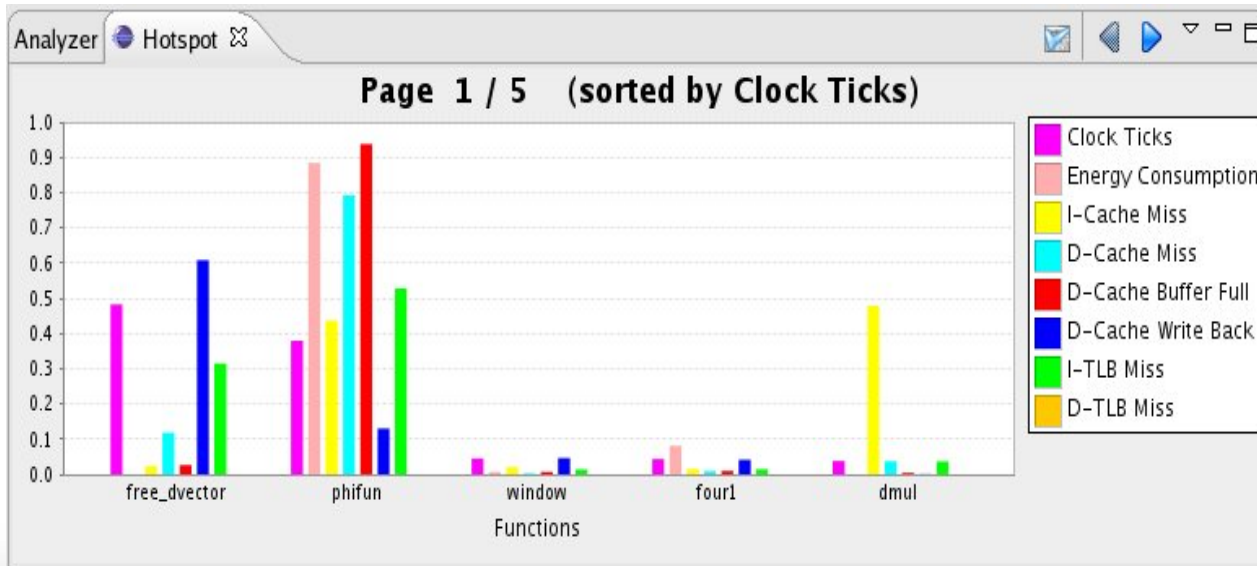


## < 실행 설정 >



# 분석 결과

Function	Source	Code Size	Energy Consumption(mJ)	Execution Time(ms)	I-Cache Miss Rate (%)	D-Cache Miss Rate (%)	CPI
amph	fmft.dius.c:1199	184	N/A	0.0479	2.0755	3.7864	9.0302
bracket	fmft.dius.c:956	624	26.5539	2.5315	0.0373	3.2353	1.7084
dindex	fmft.dius.c:1372	880	N/A	0.0302	1.1826	1.9231	4.4686
dmatrix	nrutil.dius.c:136	192	N/A	0.8849	0.9751	18.5611	9.2783
dmul	dmul.dius.c:36	828	N/A	291.2096	0.0066	41.4327	6.2972
dsort	fmft.dius.c:1212	400	N/A	0.0115	2.1818	1.5748	8.3891
dvector	nrutil.dius.c:124	60	N/A	8.3370	0.7064	4.1865	7.4218
fmft	fmft.dius.c:58	10068	52.6951	1.3469	1.0865	46.4155	26.3677
four1	fmft.dius.c:795	1124	300.3645	333.1068	0.0151	0.7114	1.4147
free_dmatr	nrutil.dius.c:198	44	N/A	0.0137	0.6569	0.9202	3.9869

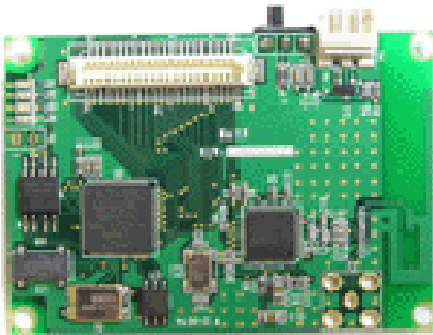


# - 센서 네트워크 시뮬레이터

# 시뮬레이션 환경 (H/W)

## ❖ Nano24(옥타컴), MICAz(Crossbow MPR2400)

- MCU : Atmel ATmega128L
- RF Transceiver : Chipcon CC2420
  - Frequency : 2.4 GHz ISM band
  - Data Rate : 250 kbps
  - IEEE 802.15.4/Zigbee 지원
  - RF Power : Rx - 19.7mA / Tx - 17.4mA



# 시뮬레이션 환경 (Nano OS)



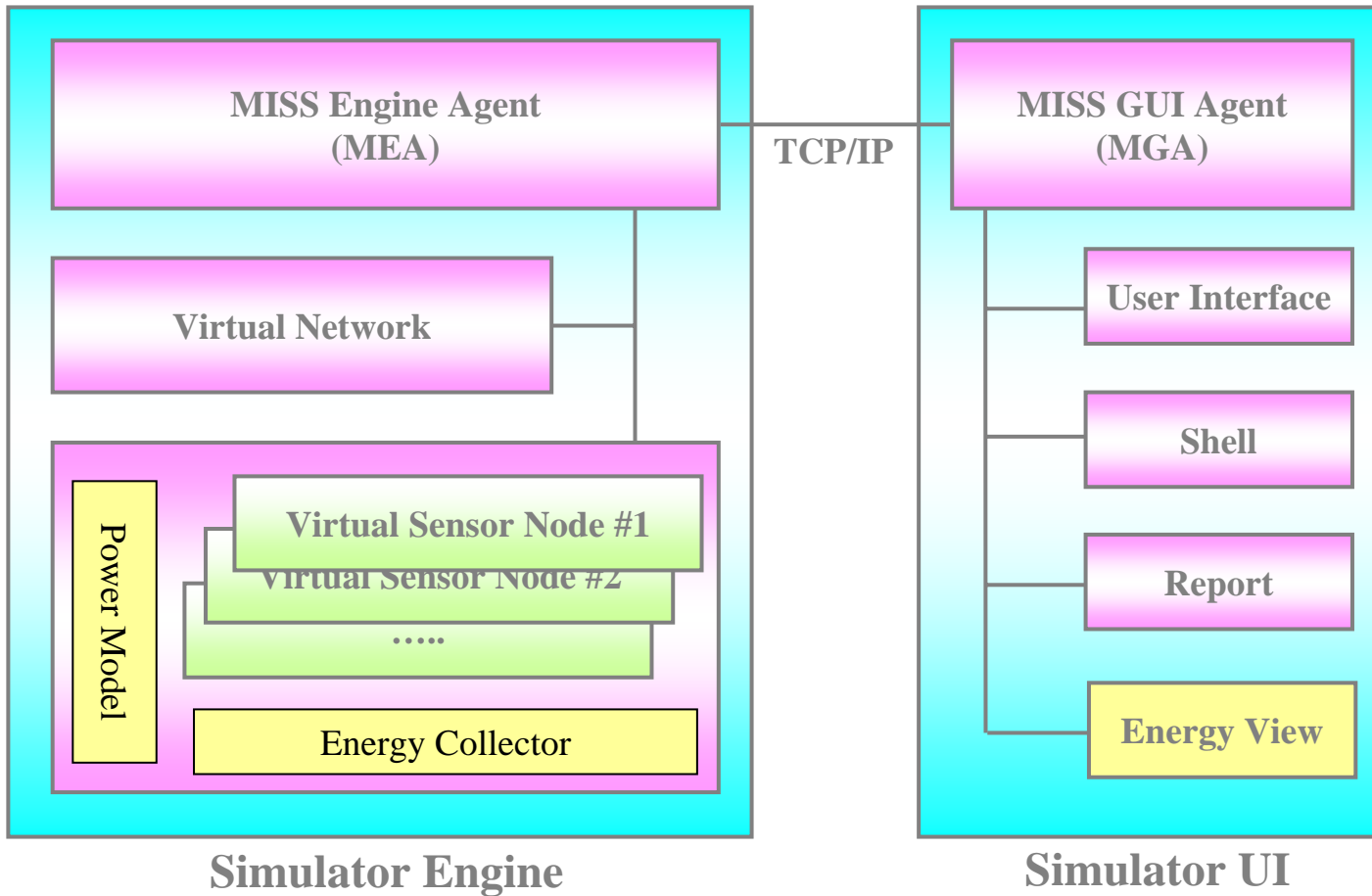
## ❖ Nano Qplus

- 한국전자통신연구원(ETRI)에서 개발
- 나노형 임베디드 운영체제
- 센서 및 actuator의 종류에 따라 OS 커널을 최적화하여 재구성 가능한 scalable OS(TinyOS 보다 향상된 S/W architecture 지원)
- 다양한 스케줄러 및 무선 통신(433, 868/916MHz, 2.4GHz, ...) 지원
- 표준형 및 마이크로 임베디드 OS와 동일한 API subset 지원(POSIX 표준 기반)

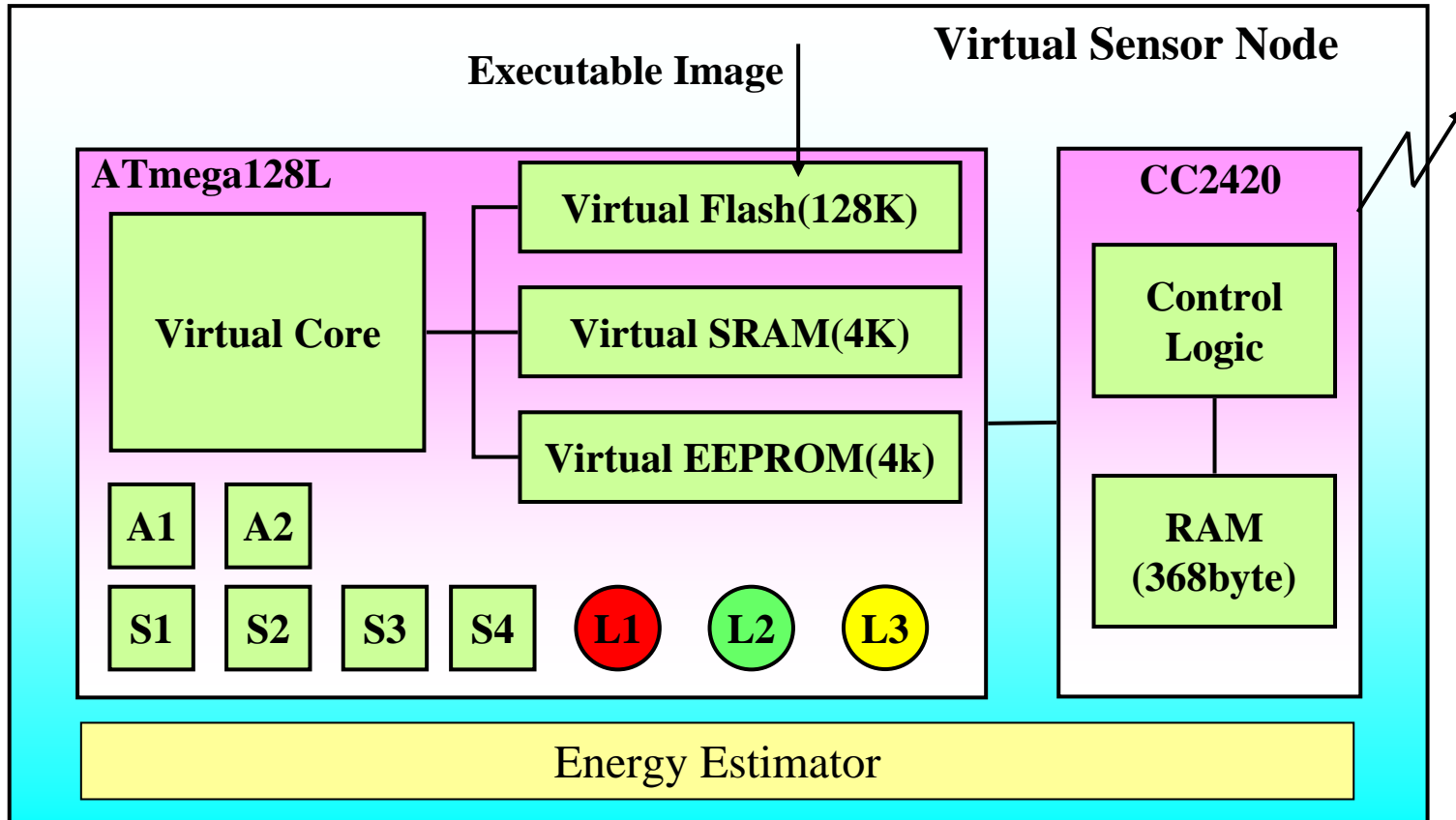
## ❖ TinyOS

- U.C.Berkeley 대학 중심의 NEST(Network Embedded Software Technology) 프로젝트에서 개발한 센서 네트워크 노드용 OS
- 작은 크기의 OS (4KB 미만의 실행 이미지)
- NesC 언어에 의하여 제공되는 컴포넌트 기반의 프로그래밍 모델로 구성
- 모든 하드웨어 자원은 컴포넌트 형태로 추상화
- 노드 간의 통신은 AM(Active Message)에 의하여 패킷 추상화

# 시뮬레이터 구조

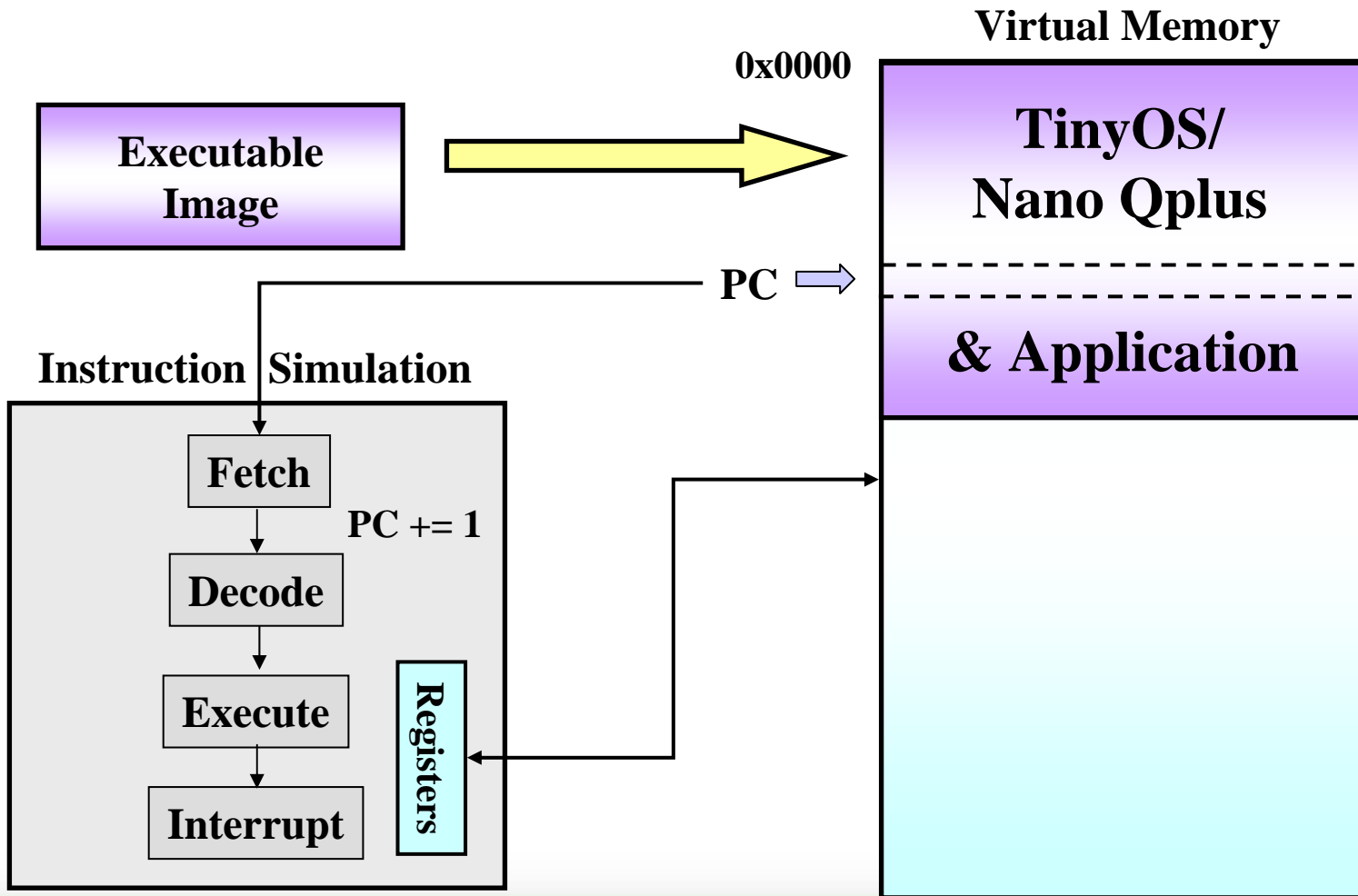


# 가상 센서 노드 구조



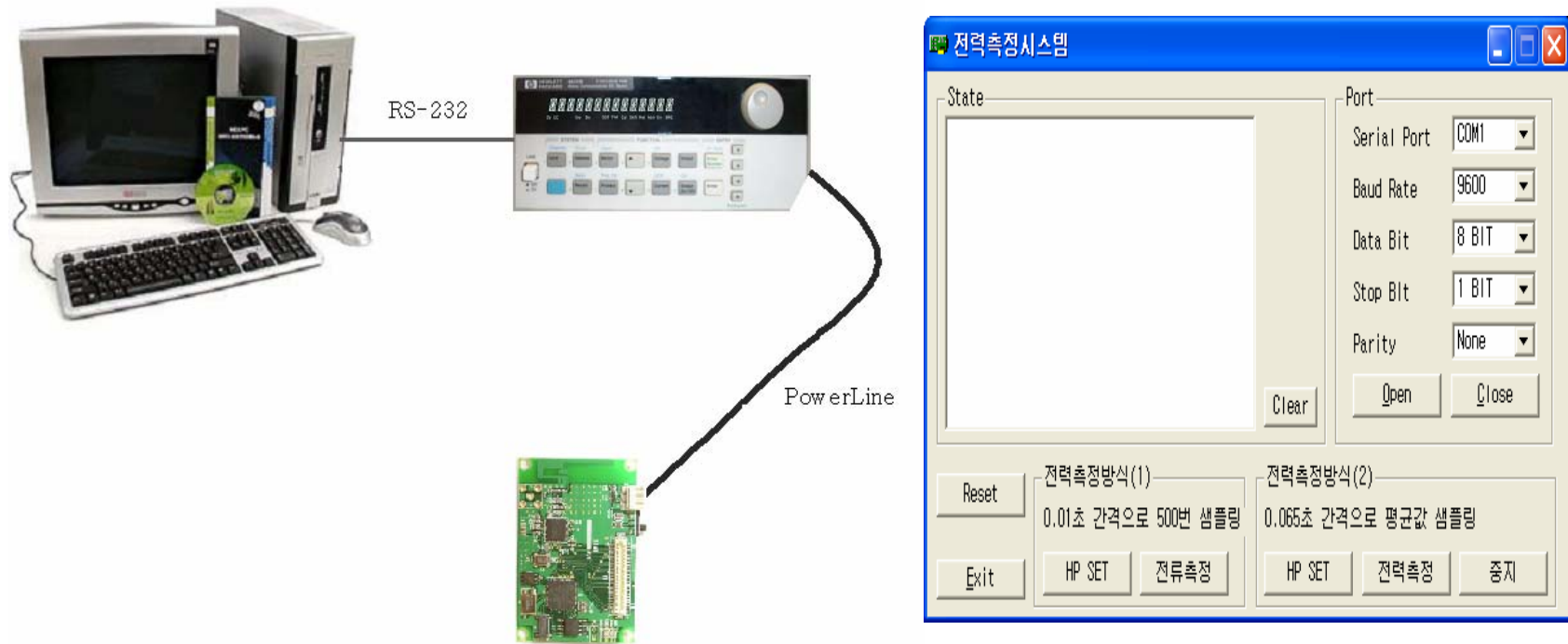
- S1, S2, S3, S4 : Virtual Sensor
- A1, A2 : Actuator
- L1, L2, L3 : LED

# 기계 명령어-레벨 시뮬레이션





# 전력 소모량 측정



- ❖ 전원 공급기를 전력 측정 시스템 프로그램으로 제어하여 원하는 샘플링 간격으로 데이터를 얻음 (전류 최대 샘플링 간격: 15.6 us)
- ❖ 측정된 실측 데이터를 기반으로 전력 소모량 분석 모델 개발

# 센서 네트워크 사용 예



# 시뮬레이션 화면

프로젝트 뷰

**노드 Outline**

- Router2
- Sink
- Router6
- Router1
- Router5
- Sensor
- Router3
- Router4

Node ID	Function	Time	Energy	MCU	Comm.	LEDData	SensorData	ActuatorD...
Router1	<Total>	1.00995	47.04762	32.10041	1.62692	13.32029	0.00000	0.00000
Router2	<Total>	0.72822	37.62862	23.14353	1.16479	13.32029	0.00000	0.00000
Router3	<Total>	1.29096	56.46968	41.03005	2.11934	13.32029	0.00000	0.00000
Router4	<Total>	1.06370	48.81361	33.80719	1.68613	13.32029	0.00000	0.00000
Router5	<Total>	0.78259	39.42464	24.87046	1.23389	13.32029	0.00000	0.00000
Router6	<Total>	1.34379	58.19108	42.70678	2.16401	13.32029	0.00000	0.00000
Sensor	<Total>	1.69602	78.13509	53.88670	2.71011	21.53828	74.24232	0.00000
Sink	<Total>	1.45294	61.80766	46.17289	2.31447	13.32029	0.00000	0.00000

MISS Running [simulation time : 8 sec, 100 milli-sec.]

에너지 뷰

# 시뮬레이션 화면 (node fault)

MISS - press [MISS] - Eclipse SDK

File Edit Navigate Search MISS Project Run Window Help

press [MISS] x detect [MISS]

detect

- .miss
- .project
- energy\_data

press

- .miss
- .project
- energy\_data

Router2  
Sink  
Router6  
Router1  
Router5  
Sensor  
Router3  
Router4

Progress Reports Engine monitor view(internal) Energy

Node ID	Function	Time	Energy	MCU	Comm.	LEDData	SensorData	ActuatorD...
Router1	<Total>	9,99367	547,73975	317,54...	140,31809	89,87190	0,00000	0,00000
Router2	<Total>	9,71320	620,20048	308,64...	225,49286	86,06271	0,00000	0,00000
Router3	<Total>	5,50152	309,19372	174,81...	35,59619	98,78103	0,00000	0,00000
Router4	<Total>	10,05749	472,05938	319,57...	57,02825	95,45860	0,00000	0,00000
Router5	<Total>	9,76980	545,03558	310,43...	154,60531	79,99814	0,00000	0,00000
Router6	<Total>	10,35163	616,89634	328,93...	209,39162	78,57352	0,00000	0,00000
Sensor	<Total>	10,67801	486,11833	339,94...	18,40744	127,76856	467,42459	0,00000
Sink	<Total>	10,40356	449,11286	330,63...	59,29719	59,17838	0,00000	0,00000

MISS Running [simulation time : 25 sec. 900 milli-sec.]

# 마치며

## ❖ 향후 개발 내용

- MCC (Mobile Convergence Computing)를 위한 Esto 기술 개발
  - DVS (Dynamic Voltage Scaling) 지원 최적화 및 분석 도구 기술
  - QoS 분석 도구 기술
  - Multi-Core 디버깅 기술
  - 원격 업그레이드 도구 기술
  - 타겟 CPU 독립적인 크로스 컴파일 기술
- 디바이스 드라이버 개발 도구 확장
- 8051 용 Nano Esto 개발
- Qplus/Esto 상용화 및 보급 확산

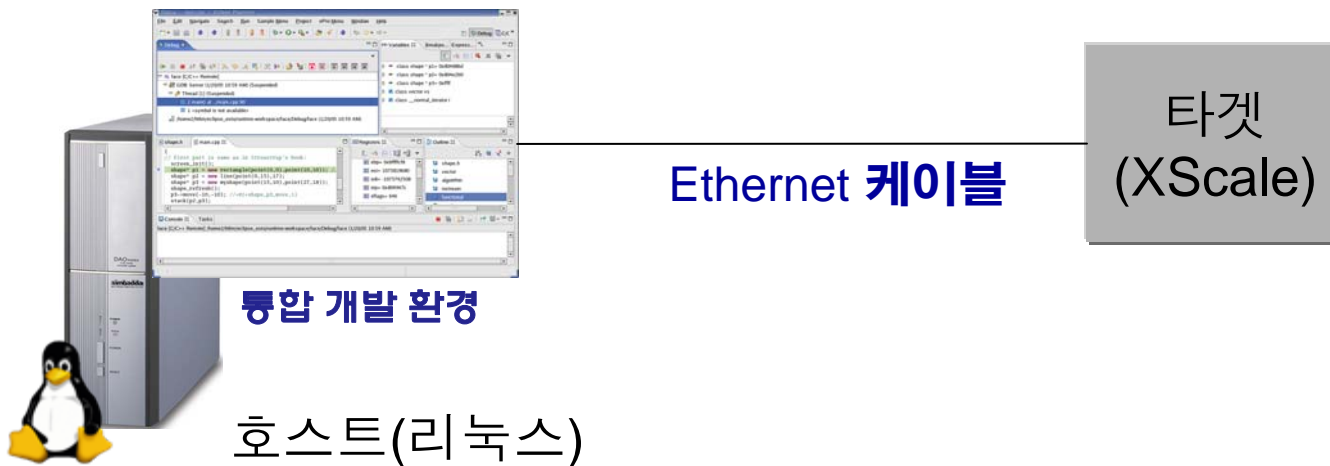
## ❖ Available in <http://qplus.or.kr>

- Esto, Qplus, Nano Qplus evaluation 버전

# - 시연

# Esto 시연

- ❖ 시연 예제 : GTK 기반 GUI 응용 프로그램
- 1. UI 수정 및 소스 코드 생성 (GUI 빌더)
- 2. 수정된 소스 코드에 대한 크로스 컴파일 (IDE)
- 3. 프로그램 정지 및 변수 값, 메모리 값 확인 및 수정 (원격 디버거)
- 4. 루프 최적화 및 성능 분석 (최적화-분석 도구)



# Nano Esto 시연

- ❖ 시연 예제 : 센서의 LED를 제어하는 Blink 예제
- 1. Blink 예제가 필요로 하는 커널 설정 및 빌드 (타겟 빌더)
- 2. Blink 프로젝트 빌드 및 시뮬레이터와 연동하여 수행 (IDE, 시뮬레이터)
- 3. 센서 네트워크 시뮬레이션 (시뮬레이터)

