SYSTEM OF SYSTEMS Engineering –

Innovations for 21st Century and

IP *Potentials*

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OUTLINE

1. **Introduction to System of systems (Cyber-Physical Systems - CPS)**
2. SoS (CPS) Engineering – *Challenges*
3. Applications – Energy, Earth, Defense, Security, Space, etc. - *Innovations*
   IP *Potentials*
4. Brief description of SoSE Research at ACE Laboratory at UTSA
5. Conclusions & More Movie Clips

Preliminary Comments

- Internet has connected people of the world since ~ 1995
- System of Systems (or Cyber-physical systems) is a generalization of connectivity of systems or systems and people – or a crossing of cyberspace and physical space!
- SoS or CPS is getting into new application cases in a very persisting pace – from IT to defense, energy, space, environment, healthcare, services, earth studies, etc.

A Definition of SoS

One out of many definitions …

SoS is a system consisting of an integration of other independent *non-homogeneous* systems with a unified goal --- improve performance measures, e.g.: cost, robustness, reliability, etc.

Applications: Environment, Energy, Defense, Automation, etc..

(Jamshidi, 2005)

What is a system of systems

Retail businesses

Freeways

Transportation SoS:
Roads +GPS+
ONSTAR

***i*POD**

Unanticipated benefits of SoS extension beyond MP3 player (Blogs, PODCAST) or Internet purchases

Others: *i*PAD

Aircraft

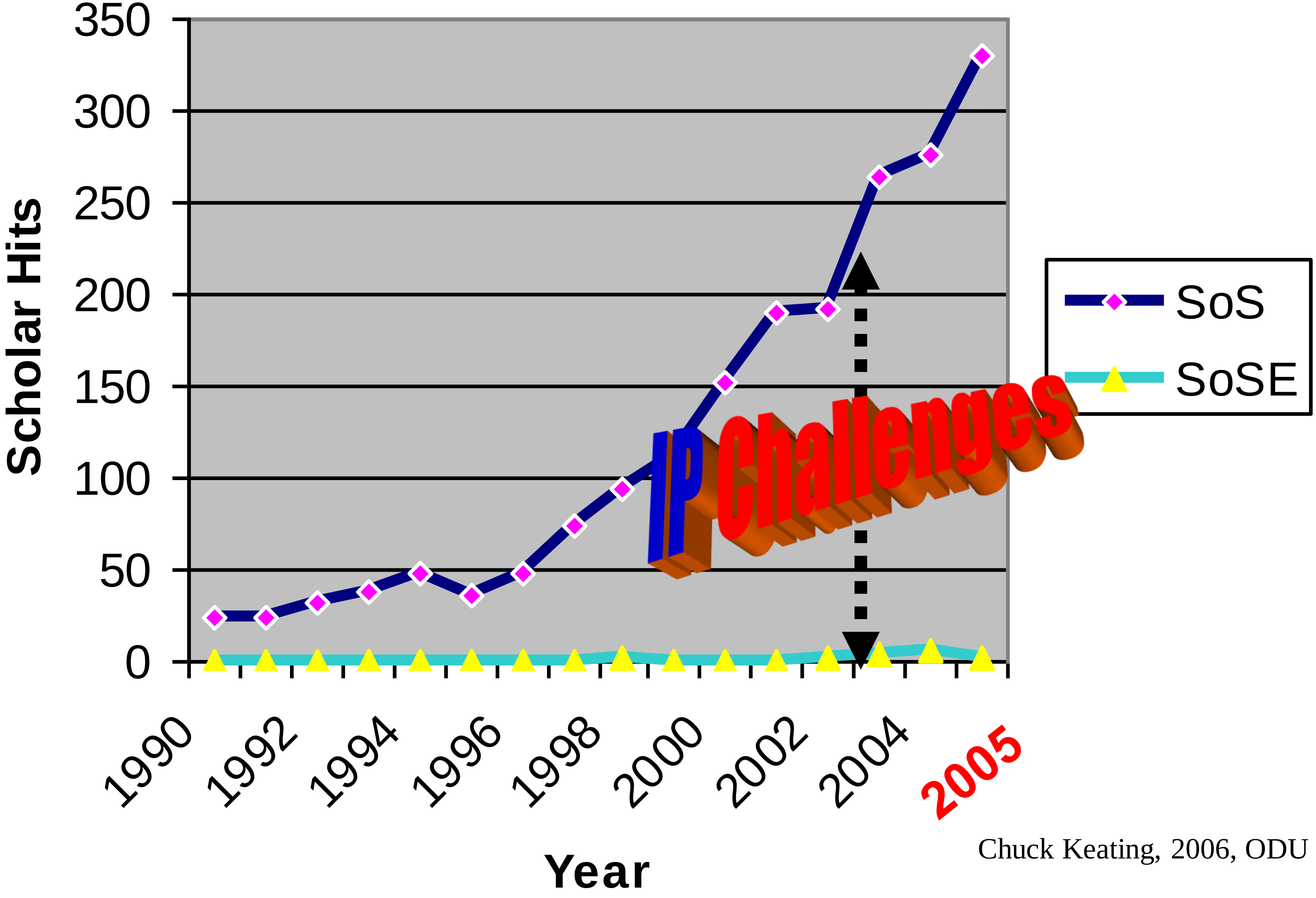
System of Systems

- **SoS**: A meta system consisting of multiple autonomous embedded complex systems that can be diverse in:
  - ✓ **Technology**
  - ✓ **Context**
  - ✓ **Operation**
  - ✓ **Geography**
  - ✓ **Conceptual frame**
- An airplane is not SoS, an airport is a SoS.
- **A robot is not a SoS, but a robotic colony (a swarm) is a SoS**
- Significant challenges:
  - **Determining the appropriate mix of independent systems**
  - **The operation of a SoS occurs in an uncertain environment**
  - **Interoperability**

Application Domains of System of Systems

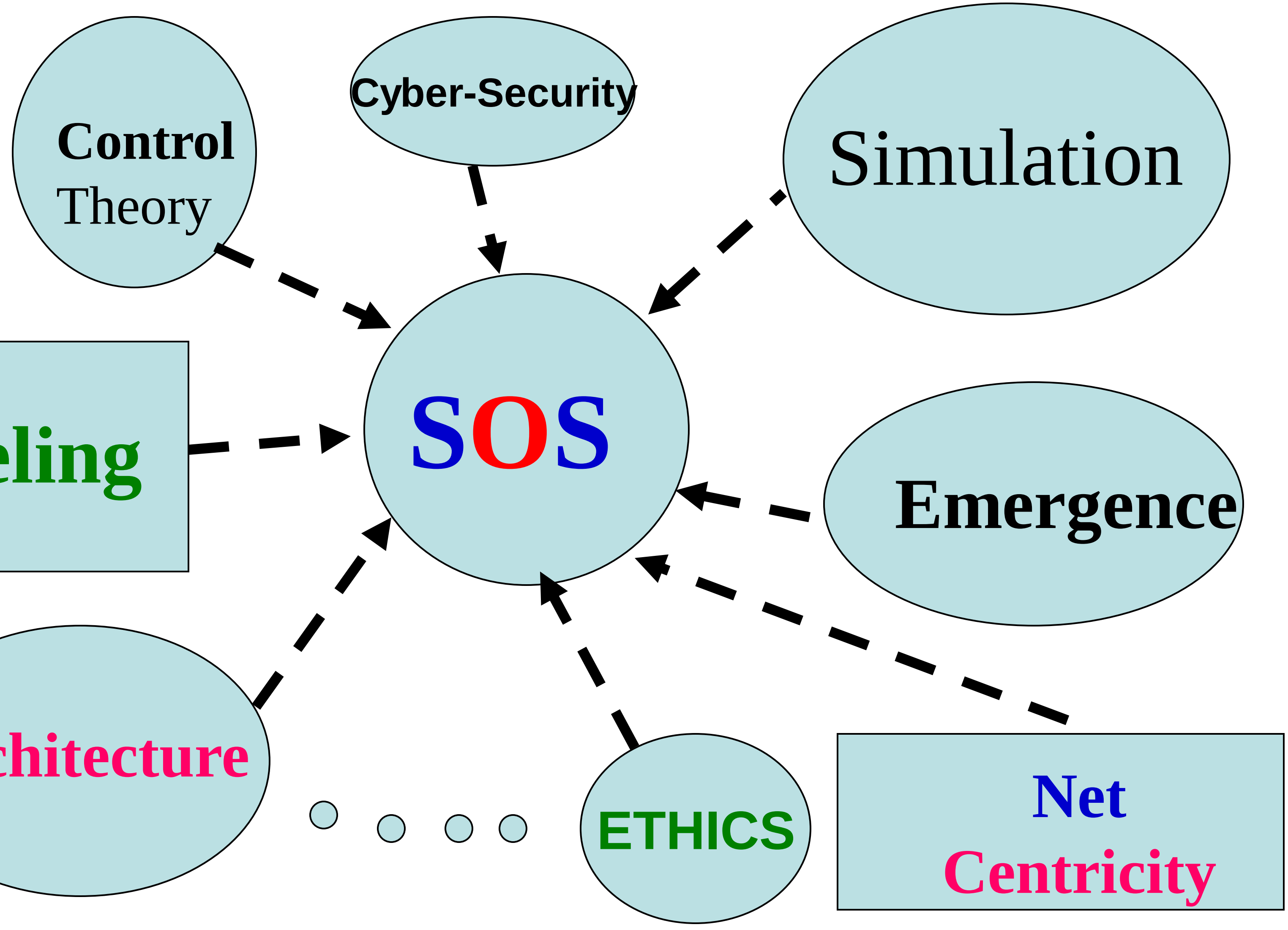
-
  1. Homeland Security – from borders and ports to natural disasters
  2. Planet Earth - GEOSS
  3. Military – future combat missions
  4. SPACE – robot colonies, formation flying objects
  5. National Security and defense
  6. Energy, fossil fuels to renewable
  7. Environment
  8. Healthcare
  9. Transportation
  10. Etc.

SoS (CPS) vs. SoSE (CPSE)



Chuck Keating, 2006, ODU

Challenges … SOS ➔ SoSE



System Engineering vs. SoS (CPS) Engineering

System Engineering is a discipline (at least 5 decades old)

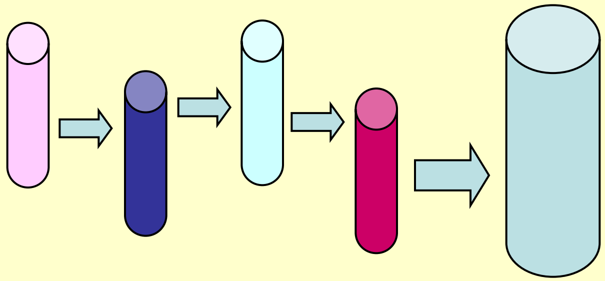
BUT

SoS (CPS) Engineering (at the present time) **is only an opportunity**

EXAMPLES
of
System of Systems

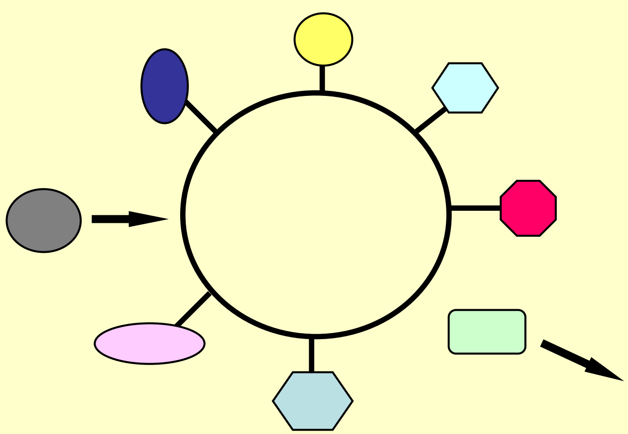
Military …What is a System of Systems

Small Stovepipes to Large Stovepipes is NOT

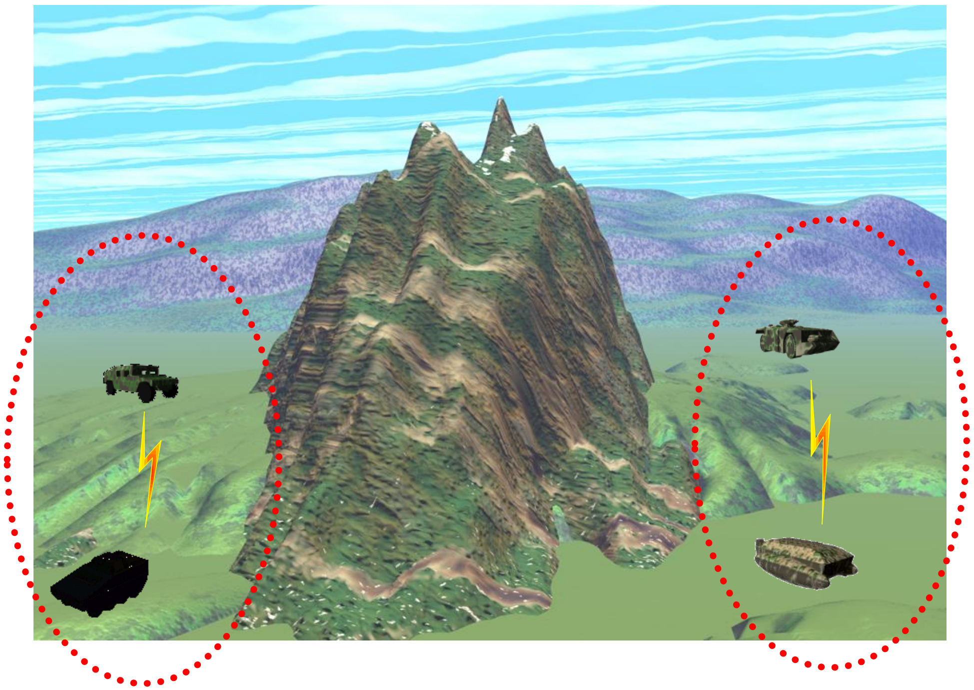


Gen. Don Walker, US Army Retired

Loosely Coupled and Tightly Integrated is what we WANT



Consider The Following



(1) A Deployed Force (and Network) Partitioned Due to Terrain Features

(2) Perform Analysis Which Yield the Initial Set of Links

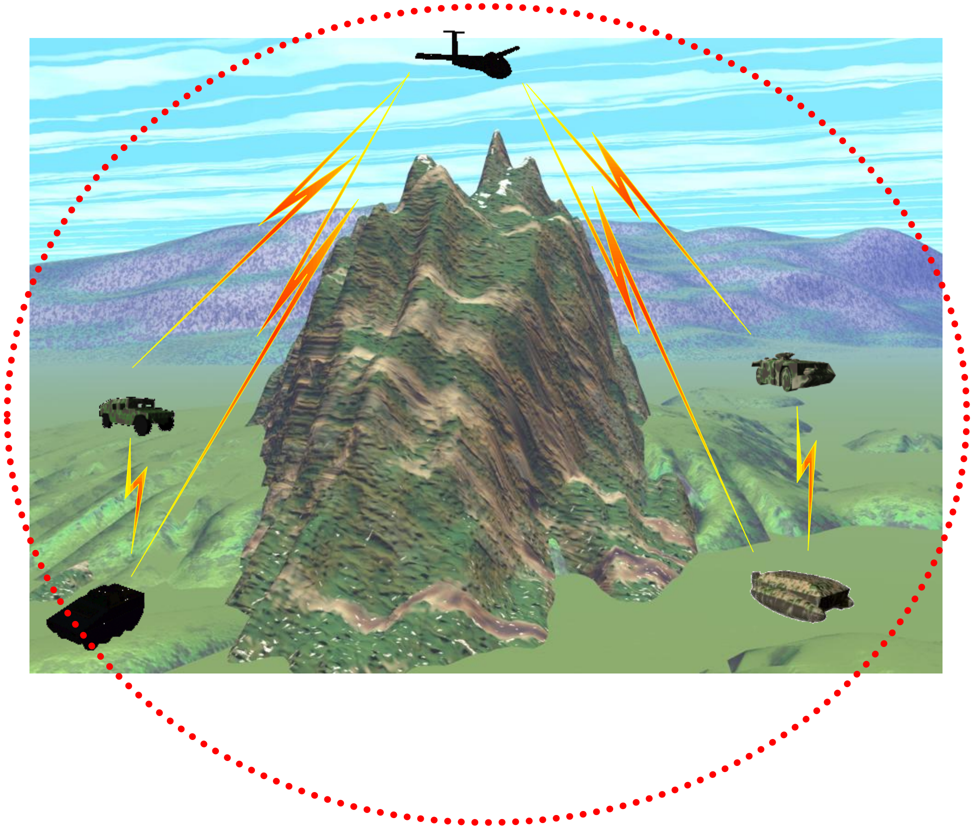
(3) Local Connectivity is Achieved, but the Forces (and Network) Are Still Partitioned

(4)
<u>Technical Enablers</u>: Algorithms, Power Profiles
<u>Example Data Sources:</u> DoDAF, Systems Book, etc
<u>Scenario Cost Implications:</u> "$Baseline 1"

(5) To Meet Operational Need, Consider Introducing an Airborne Comm Asset (UAV Flying Overhead or a Satellite Link, Depending on Coverage Constraints)

Courtesy Monica Stapleton, US Army

Consider A Change In Operations



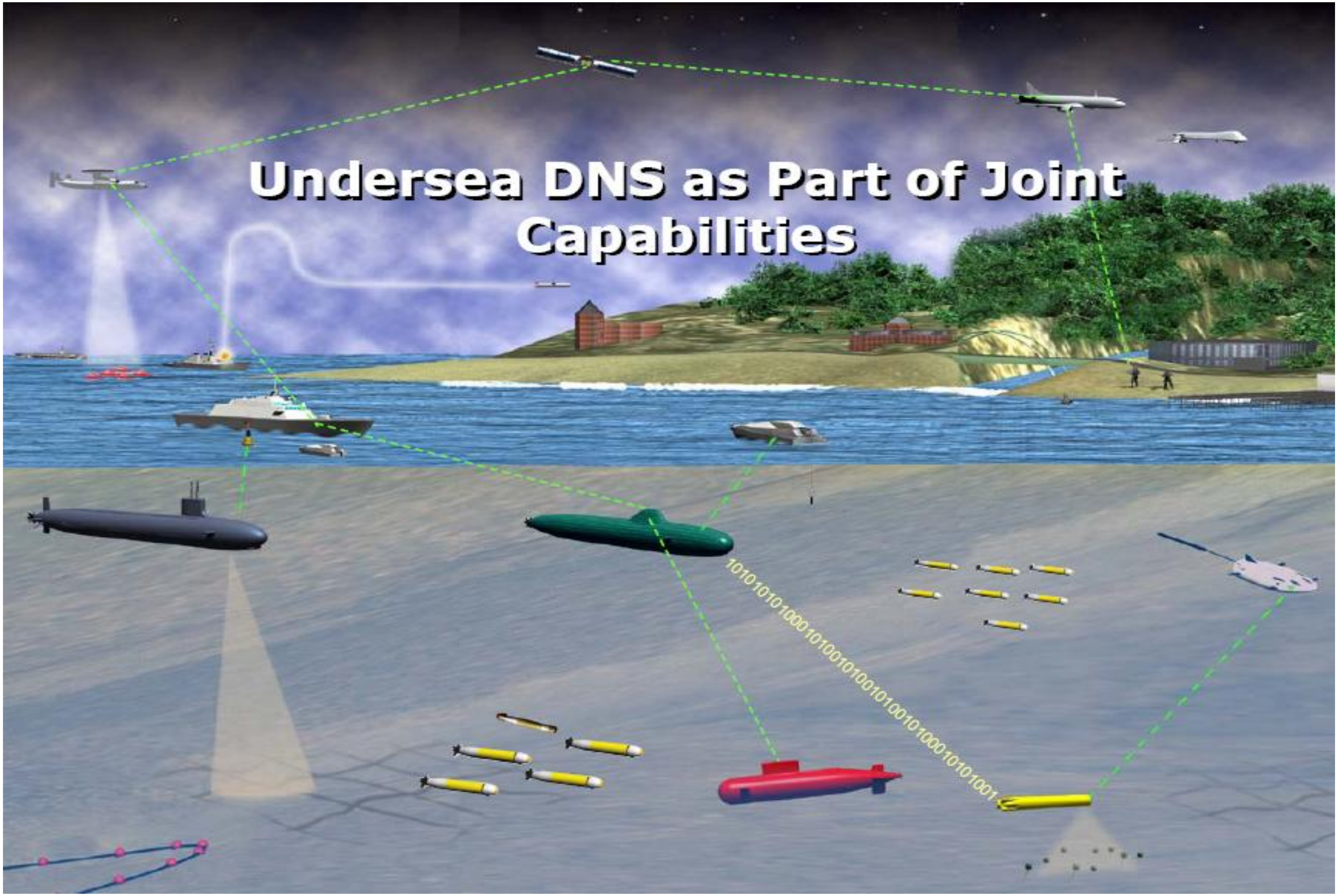
(1) Introduce a UAV Flying Overhead

(2) Perform Analysis to Determine Connectivity of Platforms Within Communications Range

(3) Networks Are Merged to Provide Full Network Connectivity

(4)
<u>Technical Enablers</u>: UAV With Comm Relay Package, Maintenance Infrastructure (Refueling, Launch/Retrieval Mechanisms)
<u>Data Sources:</u> DoDAF, Systems Book, etc
<u>Scenario Cost Implications</u>: "$Baseline 1 + UAV"

A US Navy view of SoS



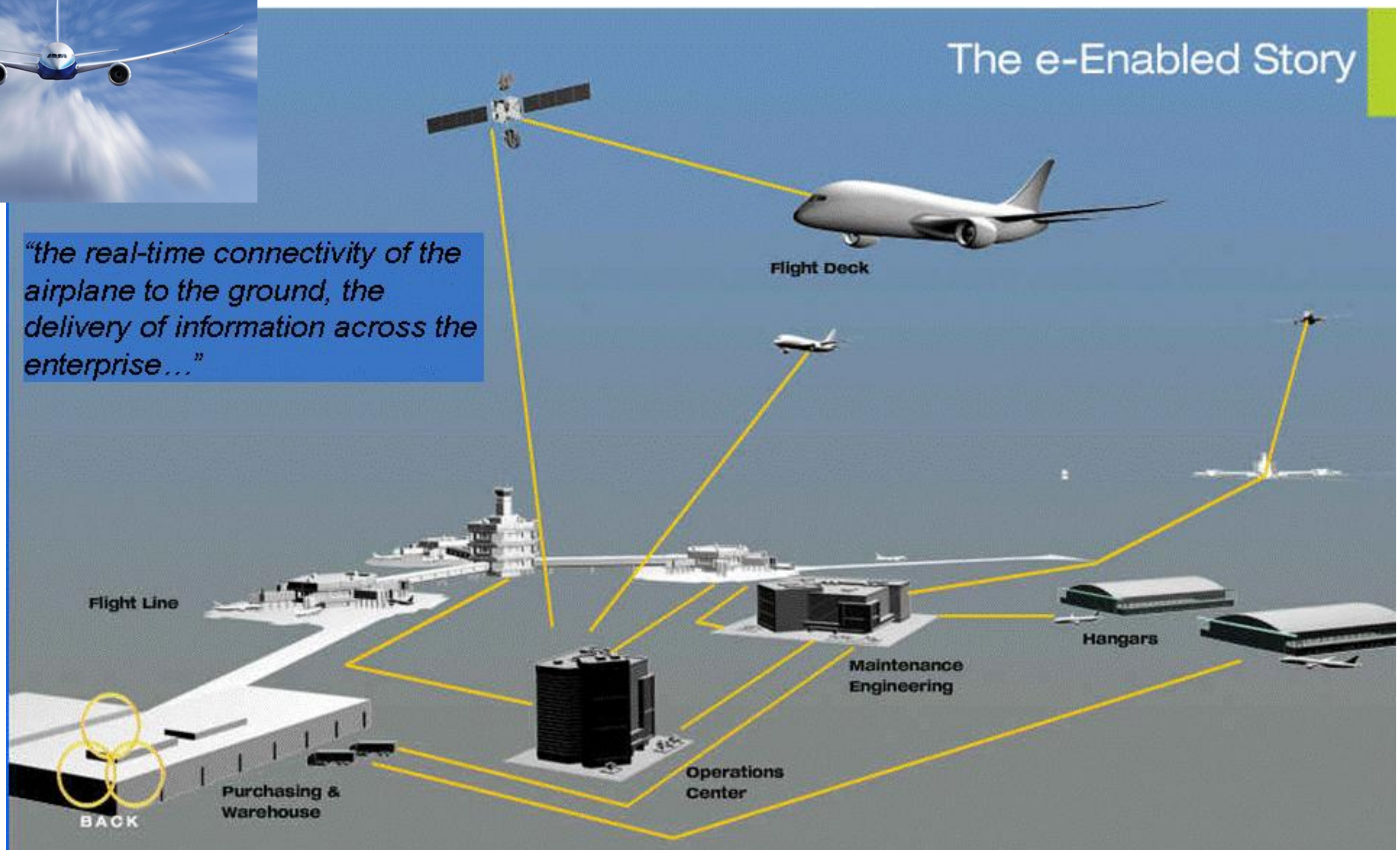
Boeing 787

(Courtesy P Gartz & Boeing Co.)

Commercial Aviation

The e-enabled Story

(G R Wilber & Boeing Co.)



Jamshidi, 2009

Planet Earth

GEOSS – Global Earth Observation SoS

Natural & Human Induced Disasters

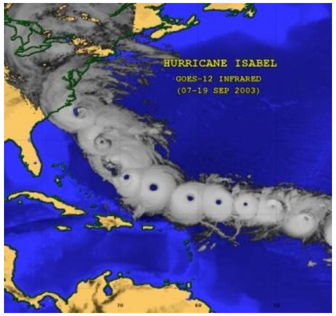
Water Resources

Ecosystems

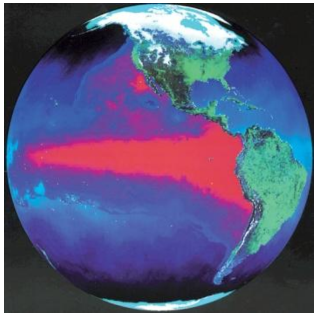
Human Health & Well-Being

Energy Resources

Sustainable Agriculture & Desertification



Weather Information and Forecasting

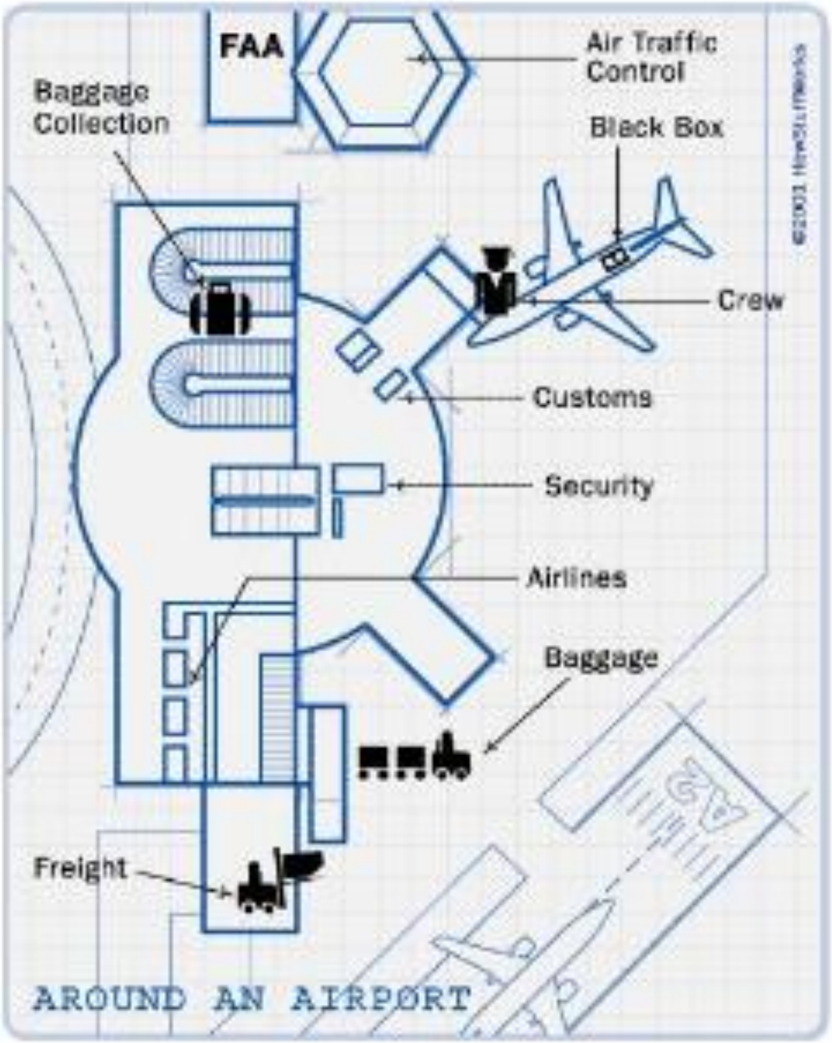


Climate Variability & Change

Oceans

Airports

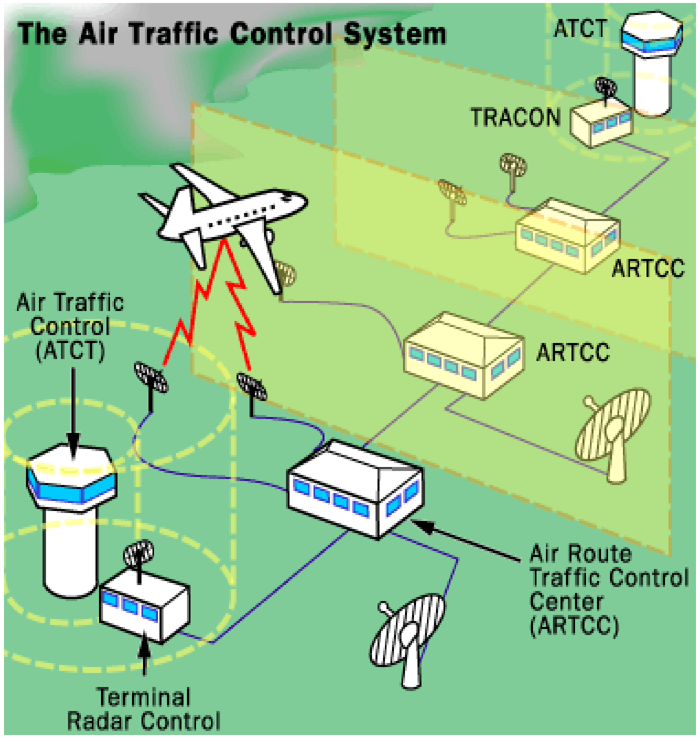
- An airport can be broken down in to smaller systems.
  - Baggage handling system
  - Air Control Tower
  - Plane w/crew
  - Freight
  - Reservation system
  - Customs
  - Security
  - Airlines



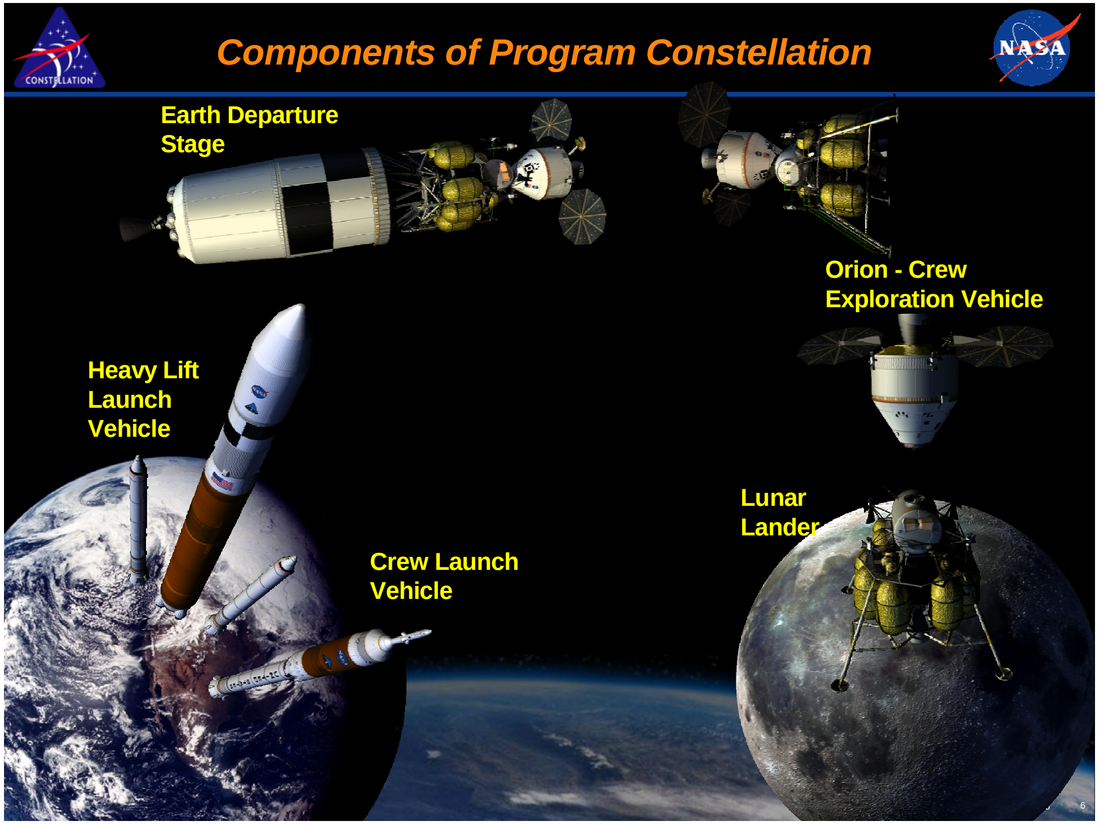
Air Traffic Control (cont.)

Air Traffic

- As plane flies, control is passed from center to center.
- In between this SoS, typically exists various Air Route Traffic Control Centers



Source – NASA Constellation Program (Co-Author Moorhead)



SOS Approach for Human Space Exploration (NASA), **Courtesy Jolly & Moorhead, 2008**

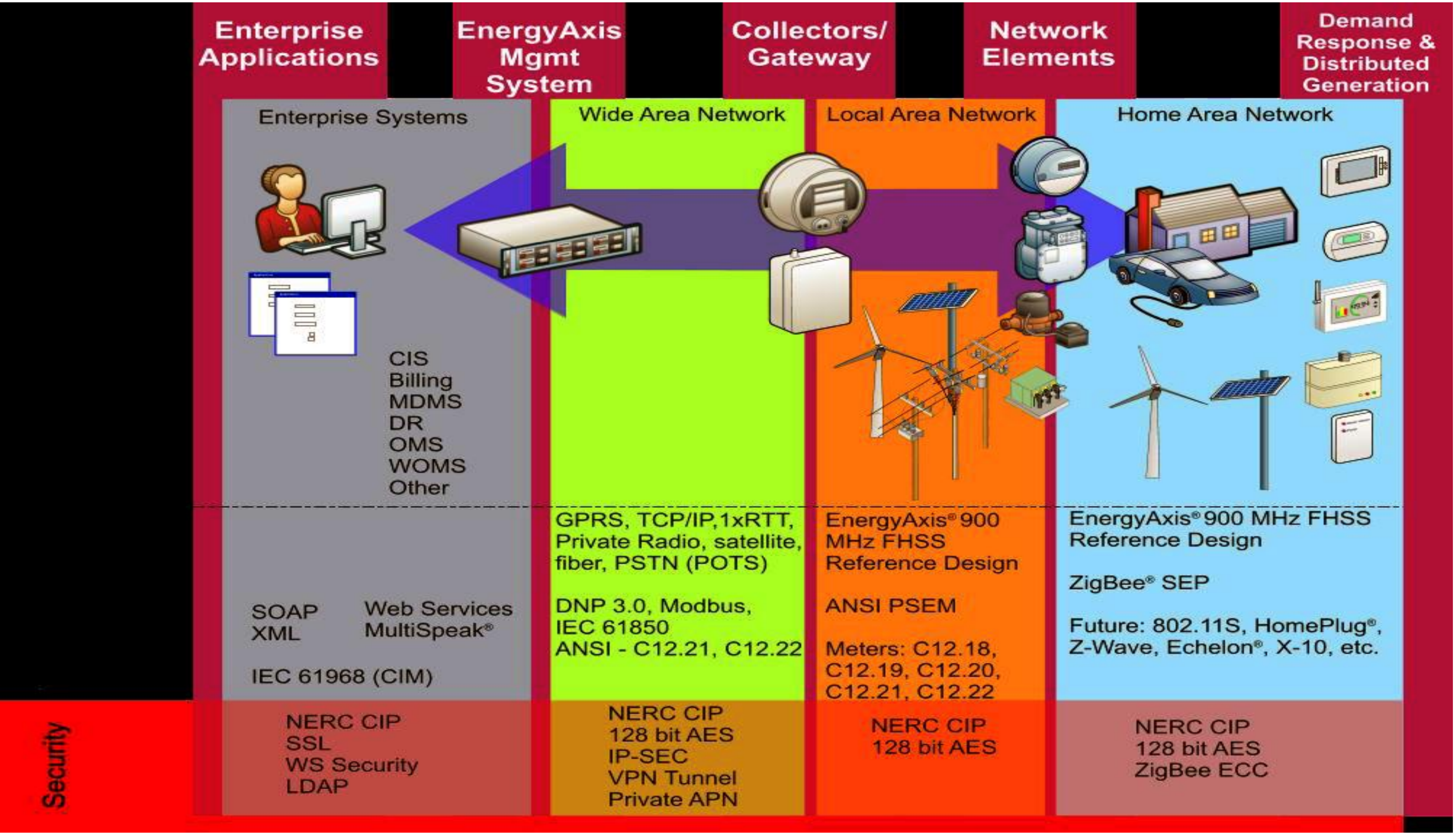


Renewable Energy



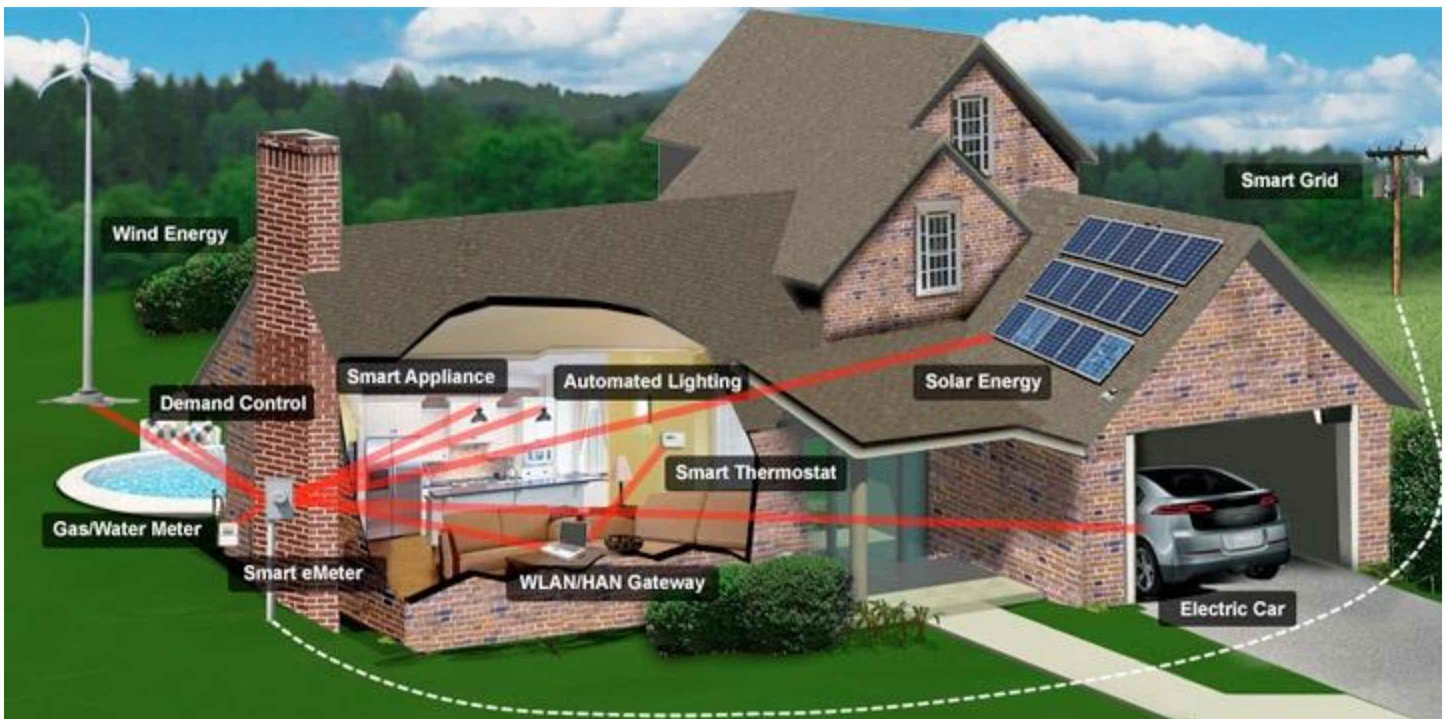
Smart-Grid Energy SoS

Smart Grids



Energy Smart Homes

Home Area Network (HAN) and Wide Area Network (WAN)



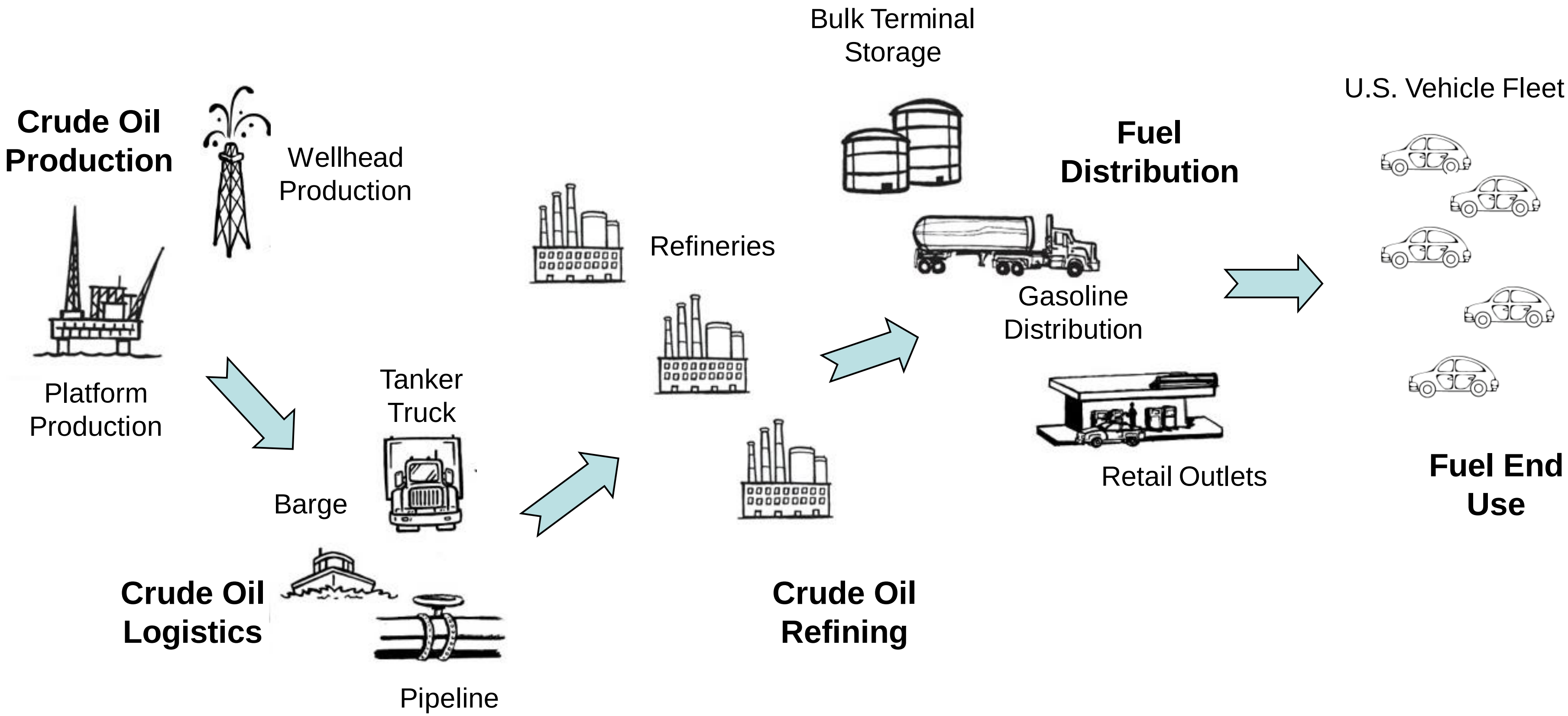
Smart Grids

What is Smart Grid?

The electric industry is poised to make the transformation from a centralized, producer-controlled network to one that is less centralized and more consumer-interactive.

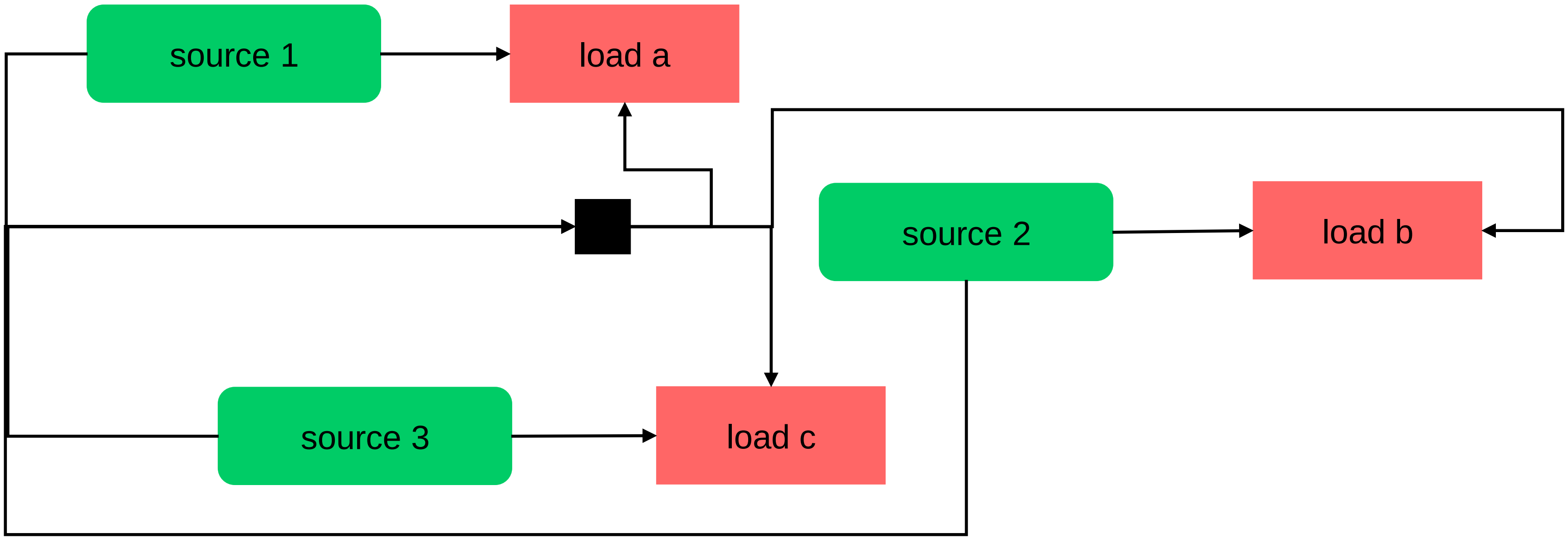
Smart Grid:

A smart grid delivers electricity from suppliers to consumers using digital technology with bidirectional communications to control appliances at consumers' homes to save energy, reduce cost and increase reliability and transparency. It overlays the electricity distribution grid with an information and net metering system.



The primary objective of each system is described in the context of the existing transportation SoS, which moves crude oil from its source to the final processed fuel used by consumers, (Duffy, et al., 2008)

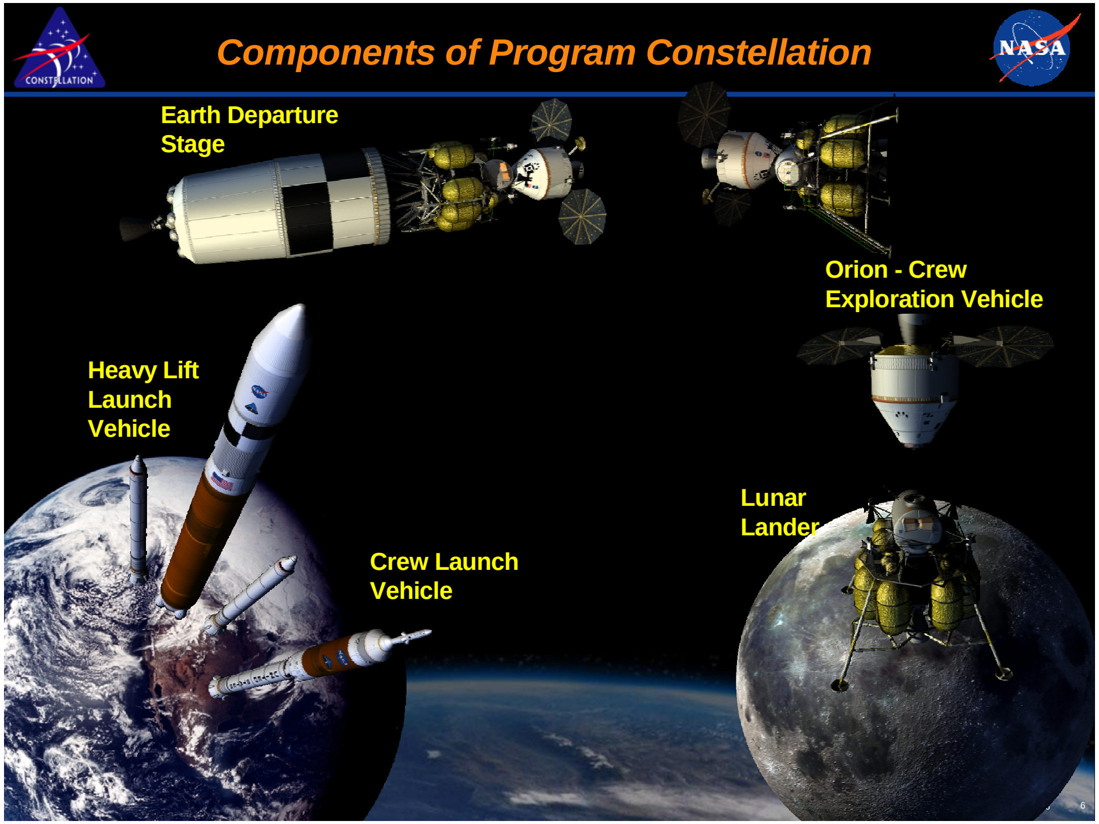
Micro Grids



In a microgrid, primary power is delivered to distributed loads from local sources as in 1st configuration, but an ancillary distribution and energy management system delivers power efficiently in low load situations and supplies important loads when their local source fail. **(Phillips, 2008)**

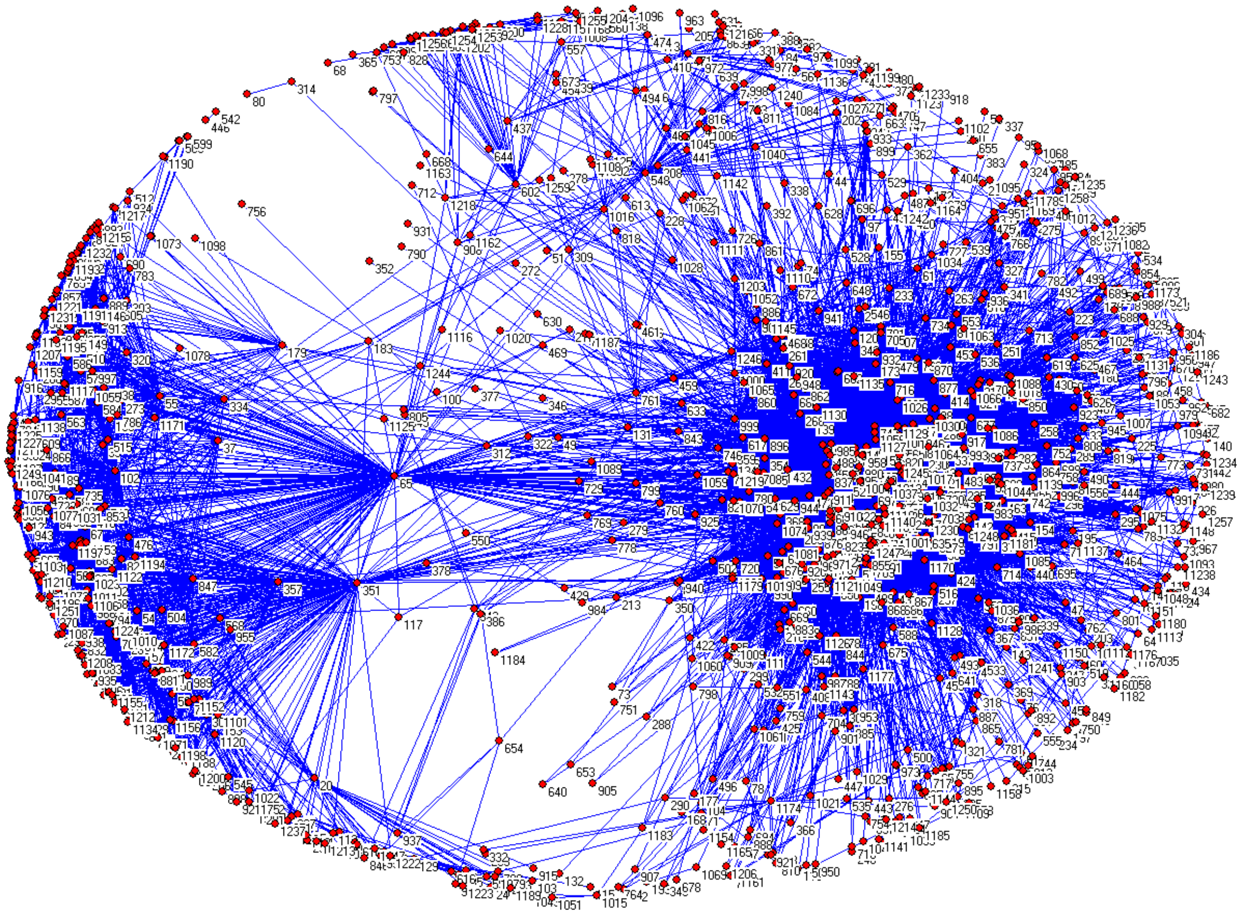
A robotic swarm is a SoS

Source – NASA Constellation Program (Co-Author Moorhead)



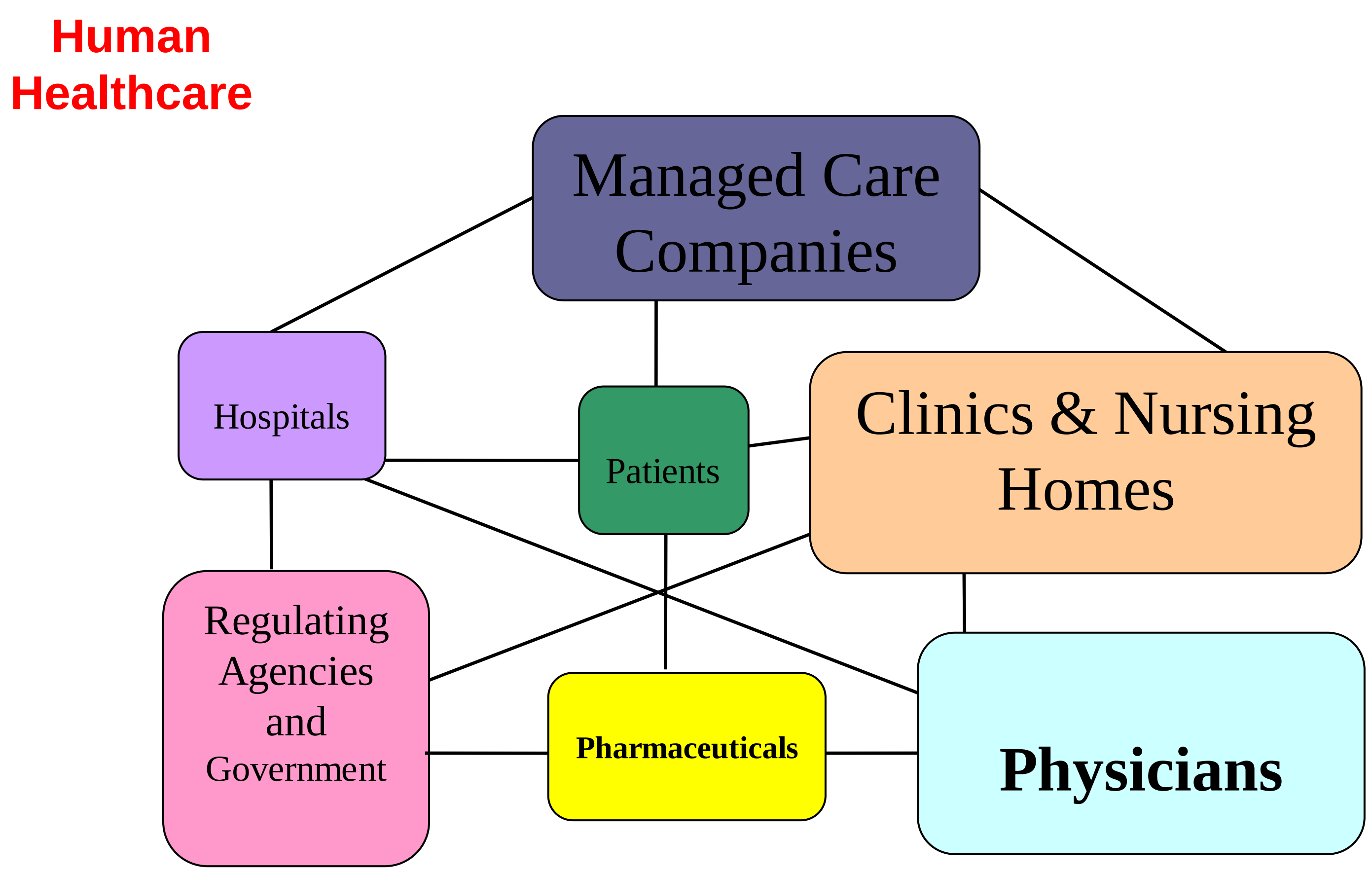
SOS Approach for Human Space Exploration (NASA), **Courtesy Jolly & Moorhead, 2008**

Transportation - Visualization of 2004 U.S. air capacity network topology (a SoS)



De Larentis, 2009

Healthcare as a SoS



Courtesy – Chalasani, et al., 2009
Jamshidi, 2009

Virtual IP's - Control Theory

1. Communication protocol effects – Network delays, how can they be handled best?
2. How can CPS remain stable in spite of data transmissions and traffic flows?
3. What new sensor can we invent to guarantee high-speed transmission of information among partner systems?
4. How will SoS architecture affect the control structure?
5. Will stability of network controlled SoS be guaranteed vis-à-vis communication.
6. How can we secure cyber space in implementing controllers?

Virtual IP's - Architecture

1. What is the best mix of systems in a SoS?
2. How can we replace a lost system in a SoS?
3. Is there a direct relation between nature of SoS constituents and their emergent behavior?
4. How do we ascertain reliability and stability of hierarchical structures of SoS?
5. How can we secure cyber space in architectures?

Virtual IP's – Modeling and Simulation

1. How to model systems w/o first principles of physics?
2. How can one simulate systems without access to traditional mathematical model?
3. How can one simulate a SoS which has only data bases and find new innovative means for data base relations?
4. How can we secure cyber space in implementing controllers?

Virtual IP's – Future Combat Missions

1. How do you choose the right mix of assets of Air Force, Navy, Army and/or Marines for a given mission?
2. How do one replace a lost system (asset) in the middle of a mission?
3. How can we secure cyber space in implementing controllers?

Virtual IP's – Smart Grids

1. **How can SoS technology fully help connect homes to cities to states and to USA in 21st Century Grid?**
2. **How can household utilize their generated energy most efficiently for a dynamic and random price of energy?**
3. **How can we secure cyber space in implementing controllers?**
4. **Other issues: Privacy issues of inter-operatability?**

Virtual IP’s – Healthcare SoS

1. How can SoS be fully utilized to create a personal health data base for a patient, while keeping privacy issue under our constraints?
2. How can a multi-objective criterion (patients need to save money, physicians want to increase their payments, providers do not like to cover you when you get sick) be implemented here?
3. How can SoS be utilized effectively to save money across the board – sharing secure health-related data across the enterprise?

Virtual IP’s – Transportation

1. How can SoS technologies be used to minimize delays in all forms of transportation? Earlier warnings, Faster dispatching, etc.
2. How can air/land transportation be interoperatable to increase efficiency, reduce cost, etc. in a metropolitan?
3. How can a system of mass transit and other public transportations be integrated to serve their communities best?

Virtual IP’s – Earth Science

1. Can SoS be giving early warning notice in advance of natural disaster like hurricanes, tsunamis’, etc.?
2. Can Weather forecasting become more reliable through SoS techniques?
3. How can Ozone layer, global warming and other Planer Earth issues can benefit from Sos technology?

Virtual IP's – Fossil Fuels

1. How can we inter-relate and inter-operate all aspects of fossil fuels from discovery to consumer usage?
2. Can SoS architecture be used for chemical properties of refined products?

Virtual IP's – National Security

1. How will inter-operatability affect our national security apparatus and methods?
2. What and how will sensor networks be modified to meet national security needs?
3. How can SoS technology enhance cyber-security?

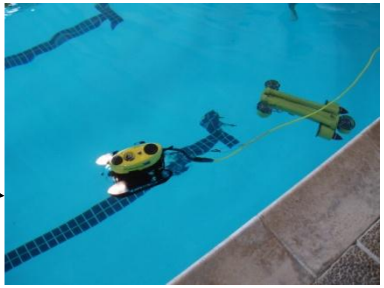
Virtual IP's – Communication

1. How can we improve the *I*-phone? The letter *I* may be used for "intelligent", for marketing purposes, but I use it because the phone is *I*-interoperatable with other systems, i.e. a SoS.
2. What about the *I*-pad?
3. Wireless ccommunication, a corner stone of SoS itself is going through constant innovations. That will impact SoS in a major way.

SoSE Research at ACE Laboratory - UTSA

Research Areas

Air-Land-Sea Rovers



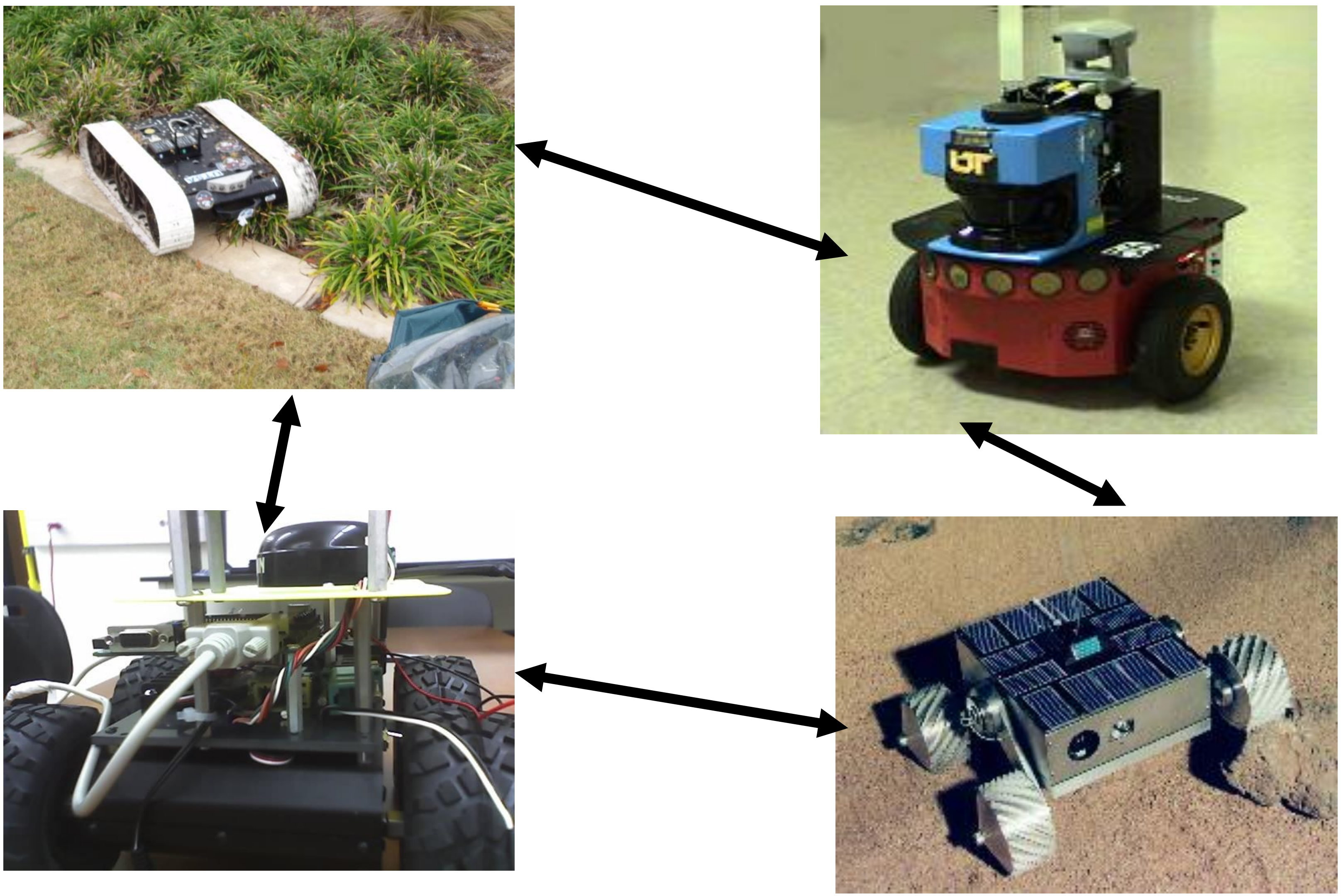
Green energy

infrastructure

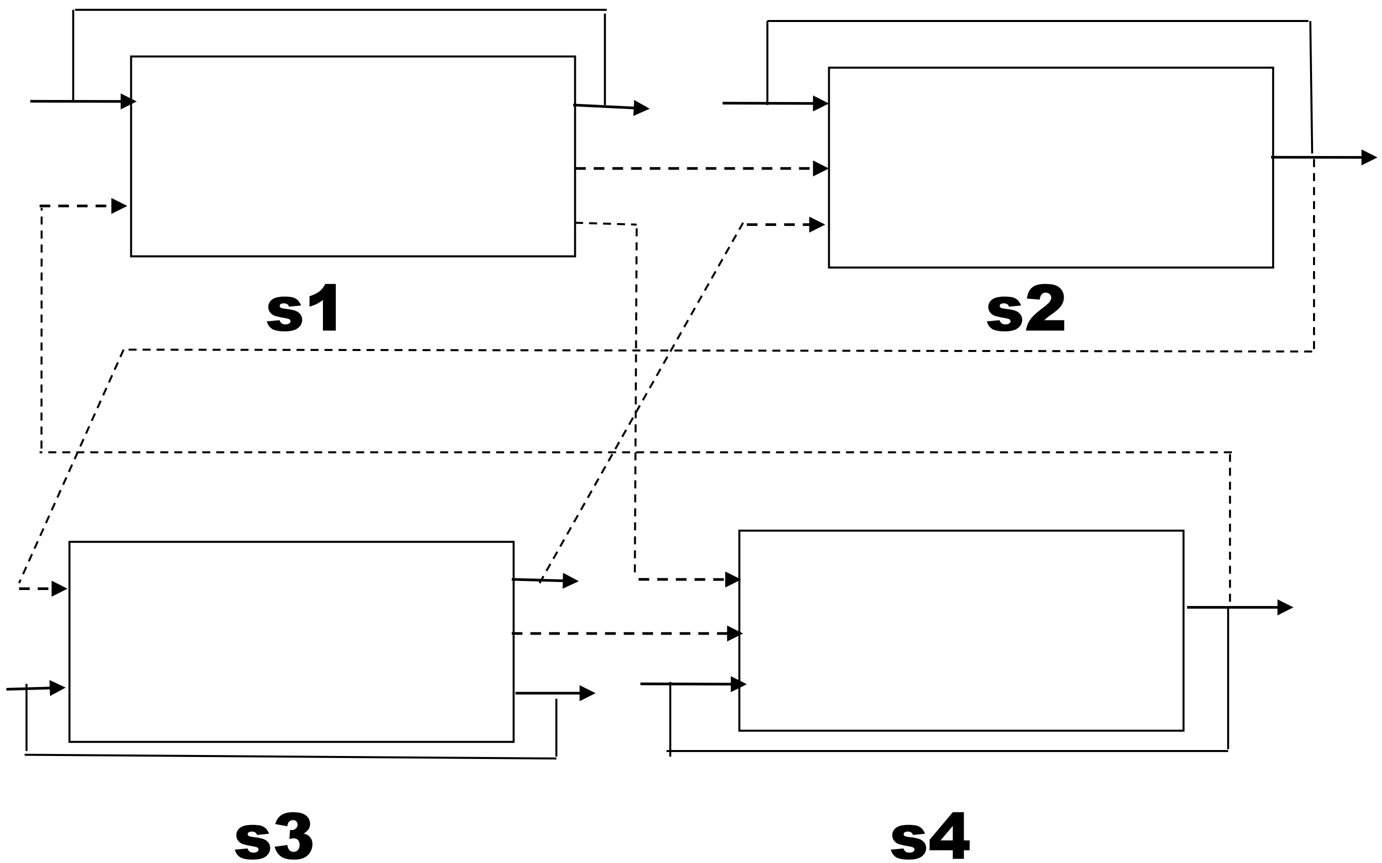
Cloud Computing

as an SoS

A Four-Rover SoS Example



A 4-sysetm SoS Example



Physical Connection

Wireless Connection

Rovers Used

1st - VideoRay

Tethered

Easy communication

PC control

2nd - ACE

Low cost/modular underwater robots

Obstacle detection/avoidance sensors

External/inertial navigation

Inter-robot communications

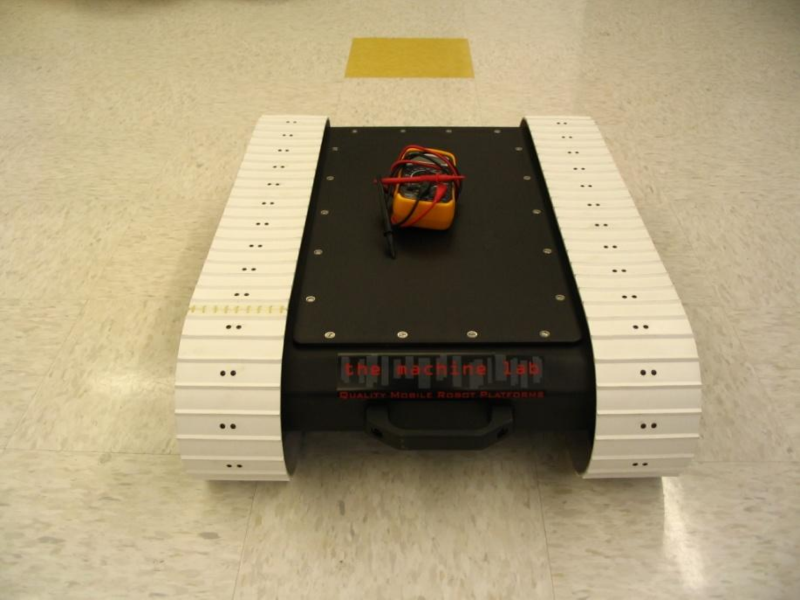
Simulation of a system of VideoRay UWV

1 VideoRay and many Simulated VideoRays following a path described by four waypoints set in a square 2m by 2m

(All are at different depths)

Joordens, et al 2008

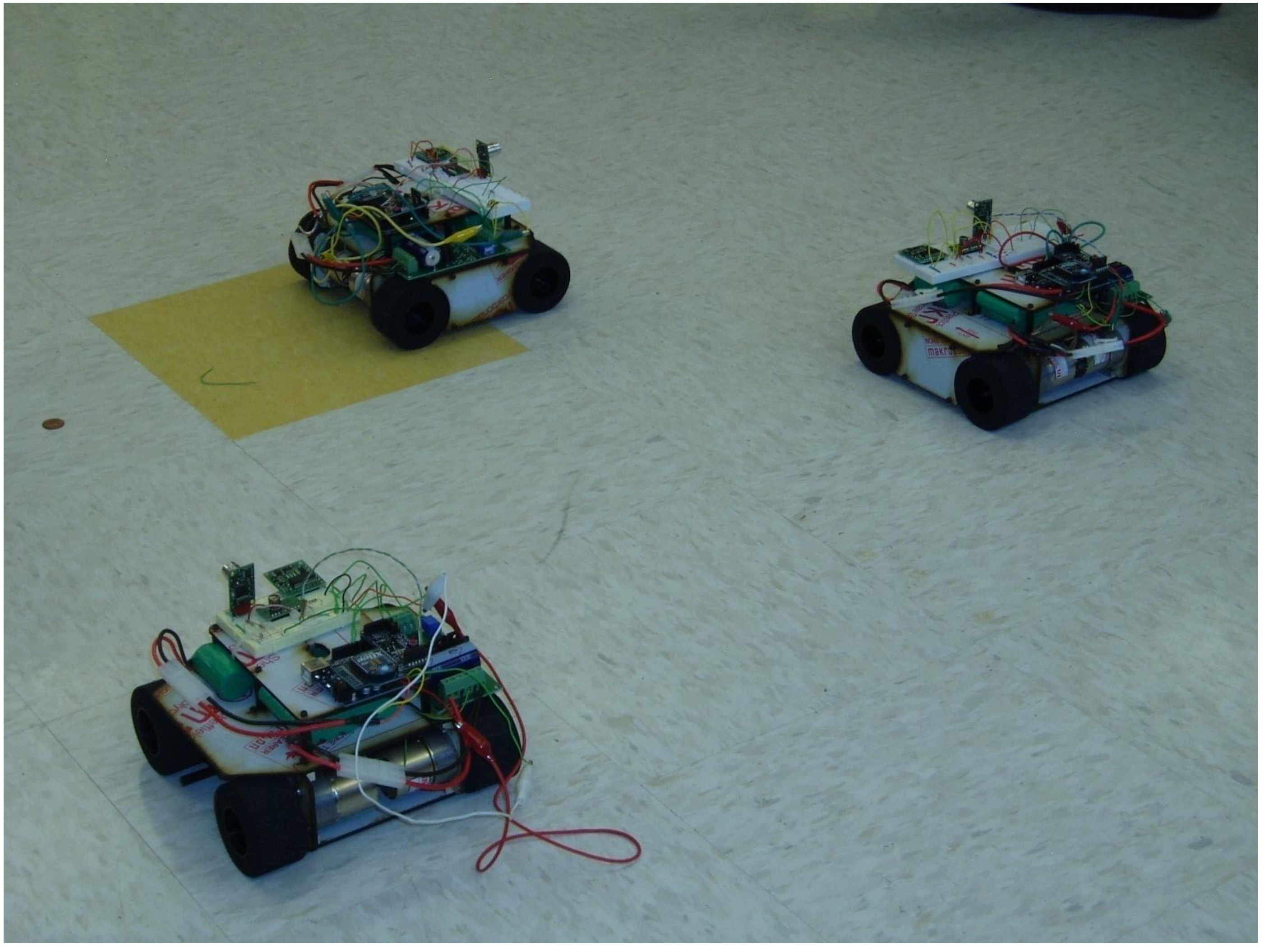
UTSA Activities



Track Rover Lone Star-1

ACE Laboratory Swarm Project

(Full version will have 26 robots)



ACE - UPM Joint work

Underwater Robotics - COLLABORTIONS WITH DEAKIN UNIVERSITY, AUSTRALIA

UTSA Activities

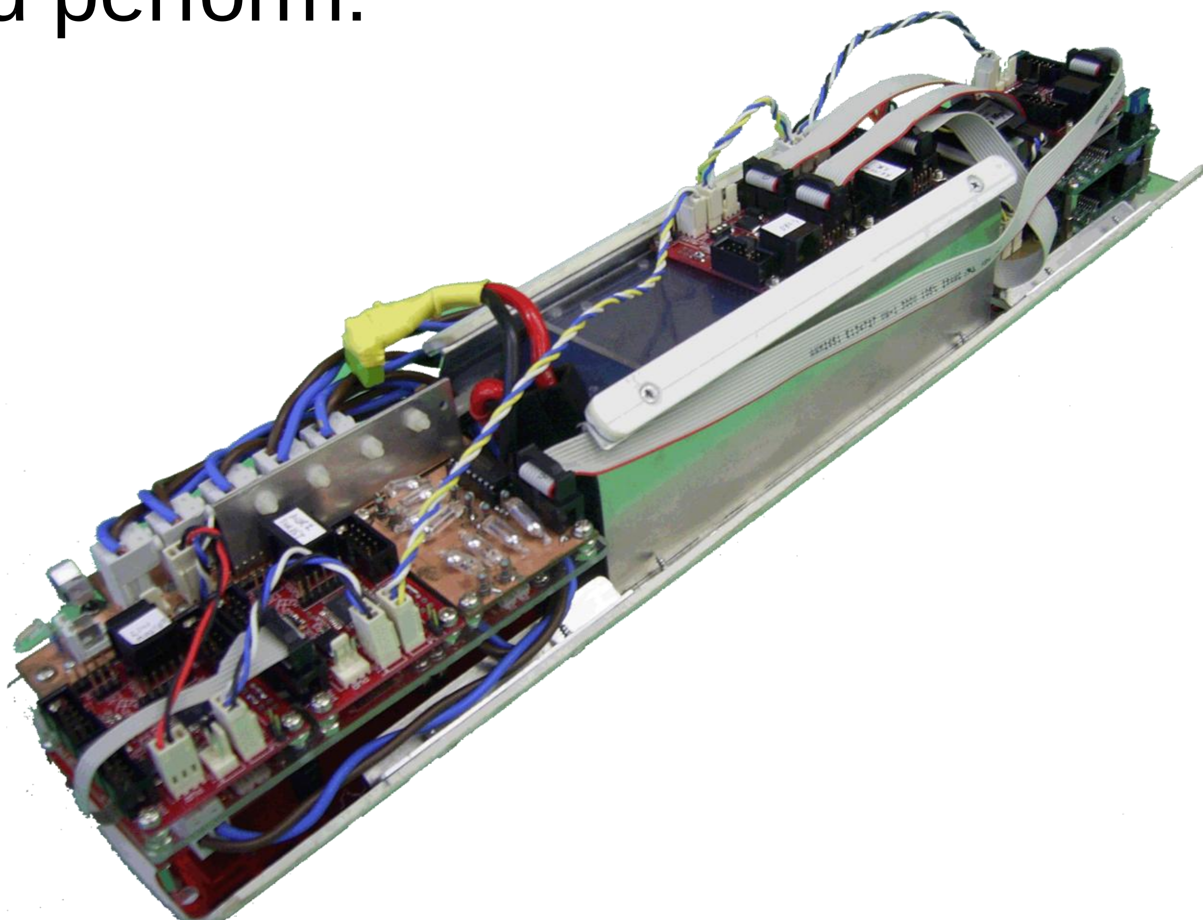
Underwater Swarm Robotics Problems

- WATER!!
- Radio does not work well underwater
- Sonar communications is very slow
- GPS does not work underwater and inertial navigation can be inaccurate
- Visibility can be very poor
- 3D environment
- Electricity/Water don’t mix

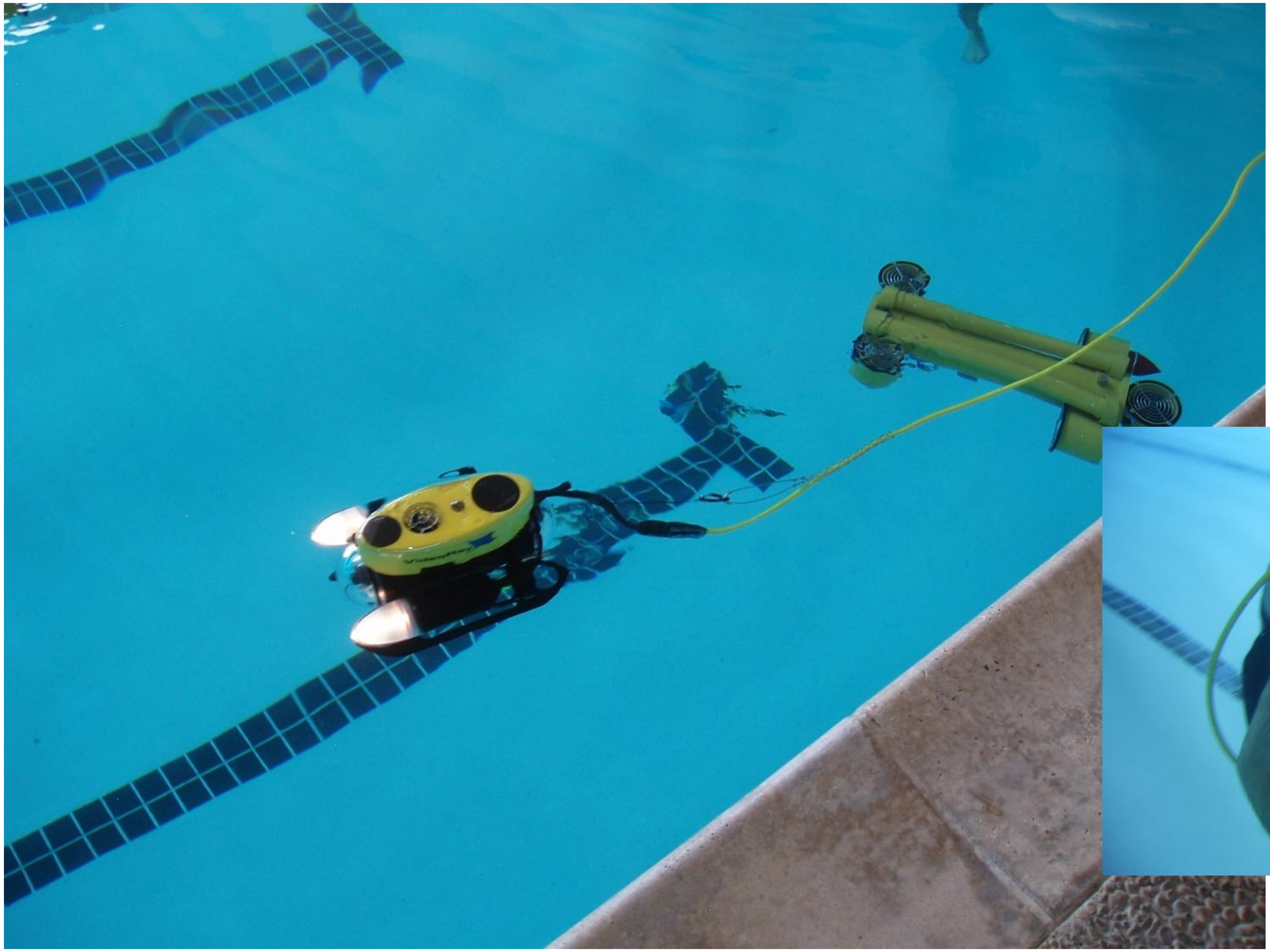
Underwater Swarm Robotics Applications

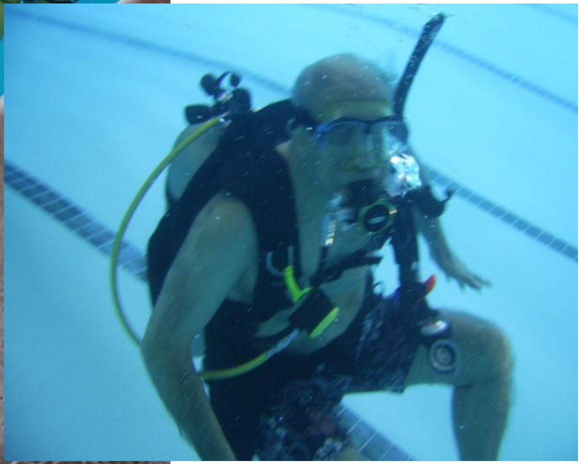
UTSA Activities

- A swarm could perform:
- Inspection
- Search
- Rescue
- Mining
- Salvage



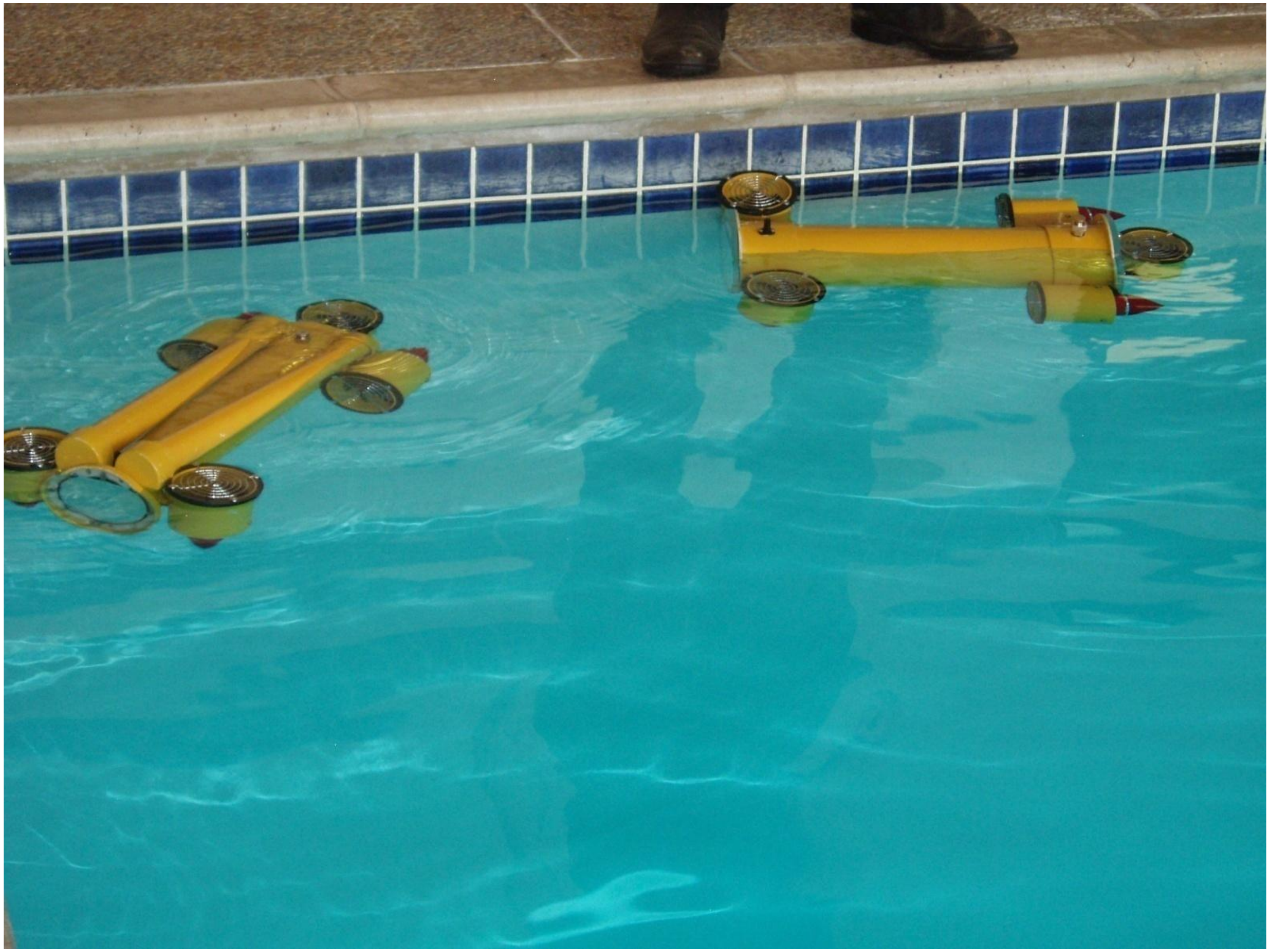
Underwater Rovers





A system of UWV – underwater vehicles for sensing and security.

Underwater Rovers



A system of UWV – underwater vehicles for sensing and security.

Underwater Rovers

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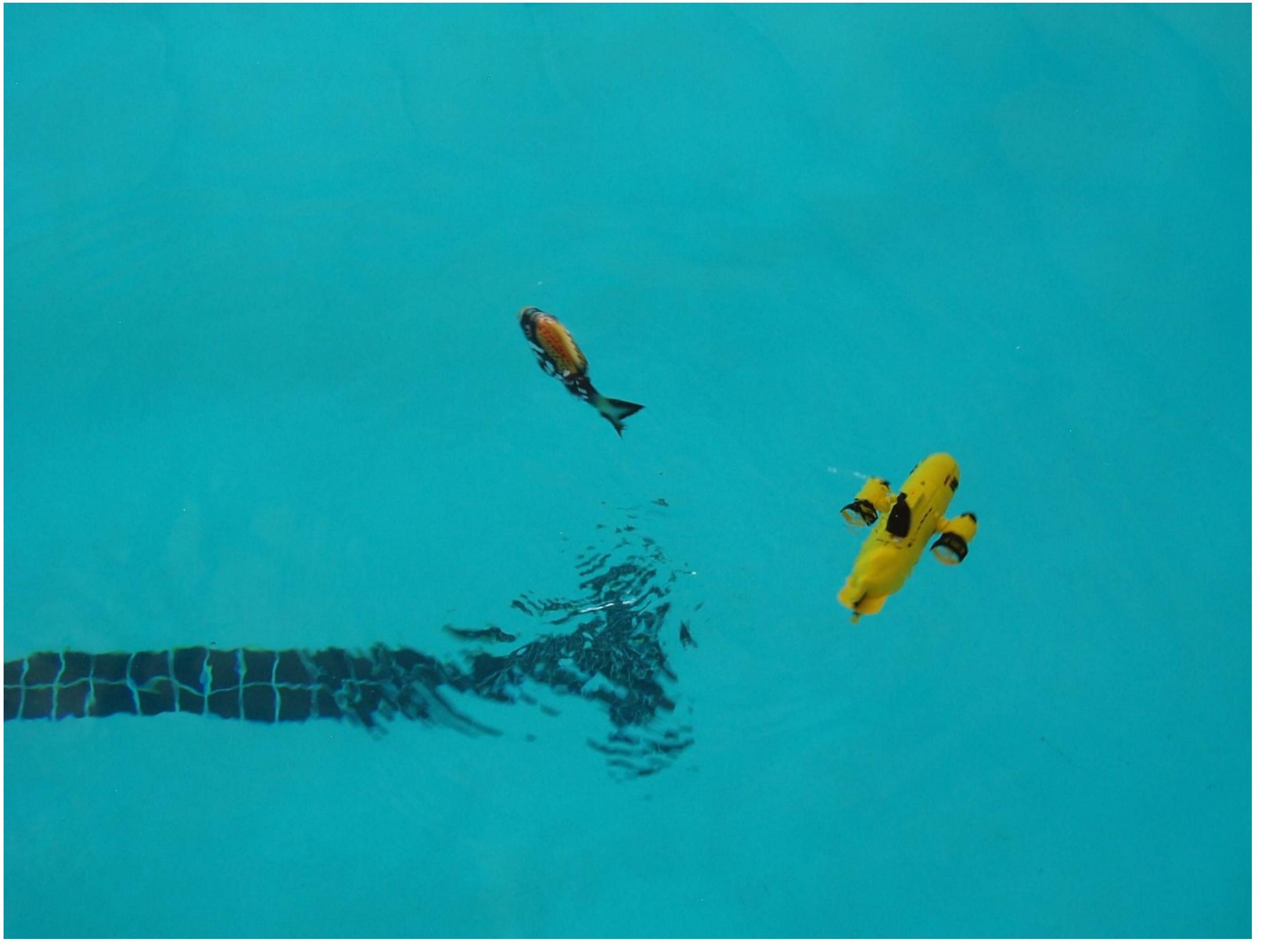
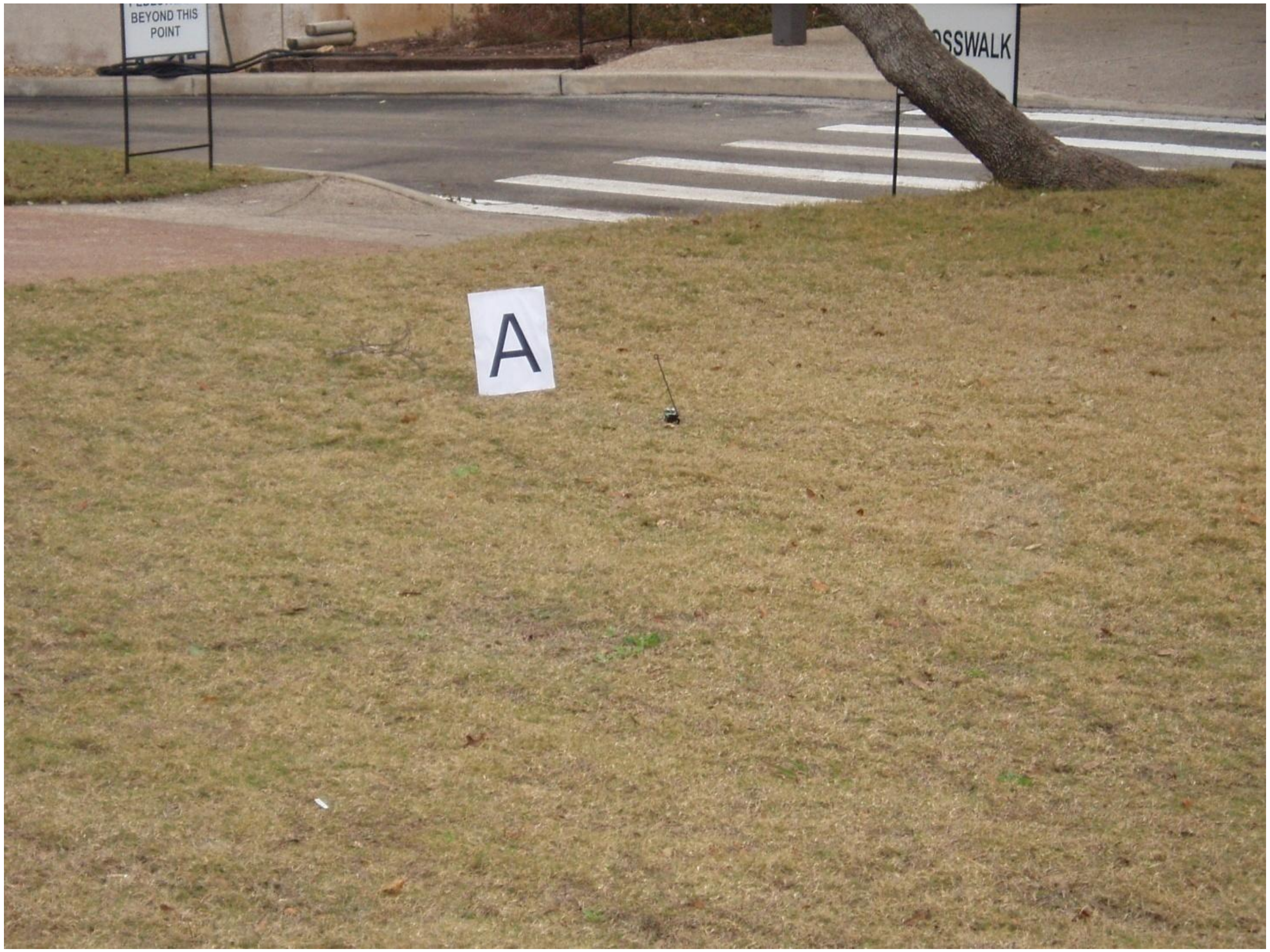
Underwater Rovers



A system of UWV – underwater vehicles for sensing and security.

PBS Television ON TEXAS STATIONS



An alarming condition is observed in sensor network

PBS TEXAS STATIONS DEMO

Through remote sensing capability the master rover picks up the alarm

PBS TEXAS STATIONS DEMO

Haptic Controlled Rover requests an scout rover to check the authenticity of danger

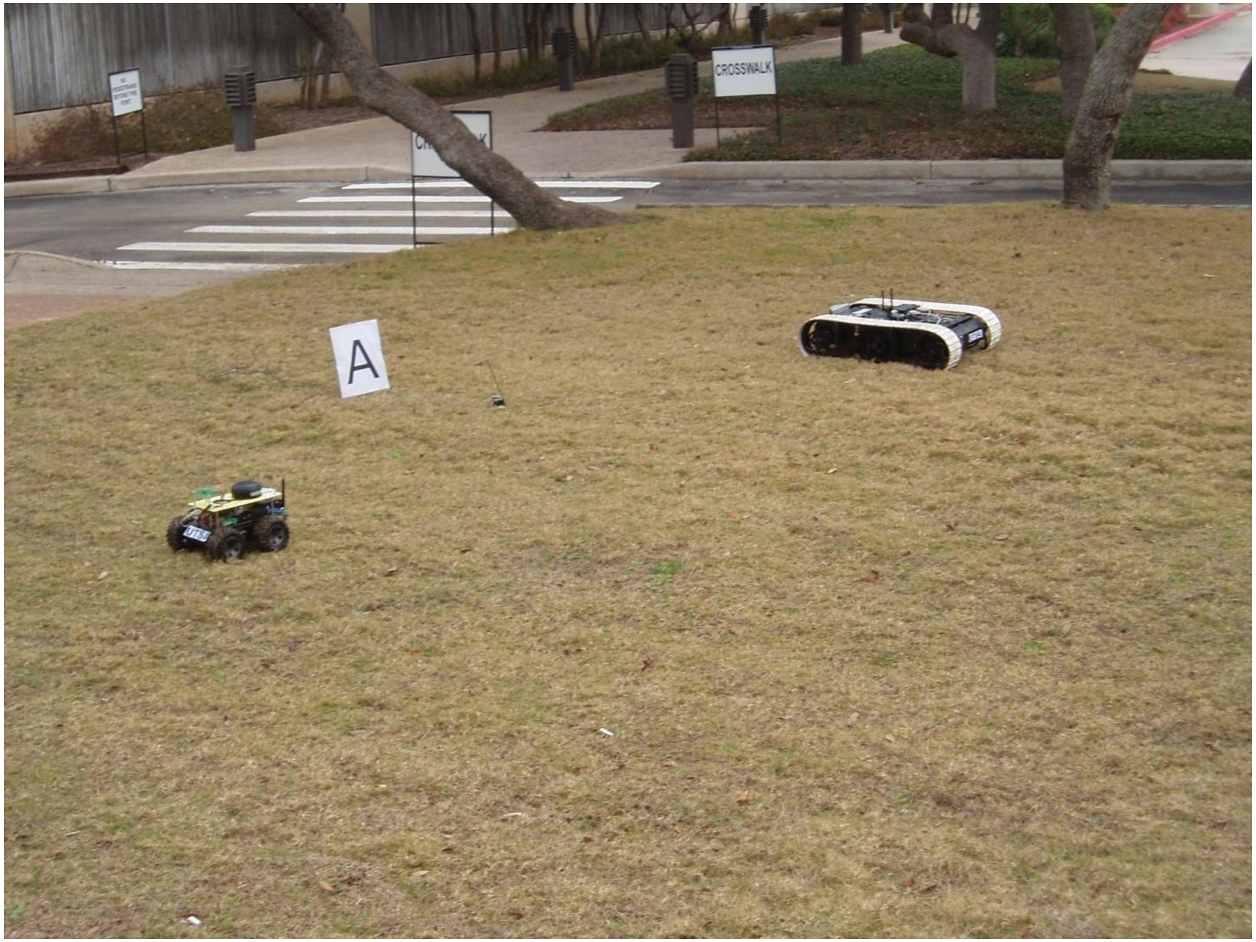
PBS TEXAS STATIONS DEMO

Scout Rover is on its way under GPS navigation to check on the danger

PBS TEXAS STATIONS DEMO

Scout Rover has found the danger spot

PBS TEXAS STATIONS DEMO



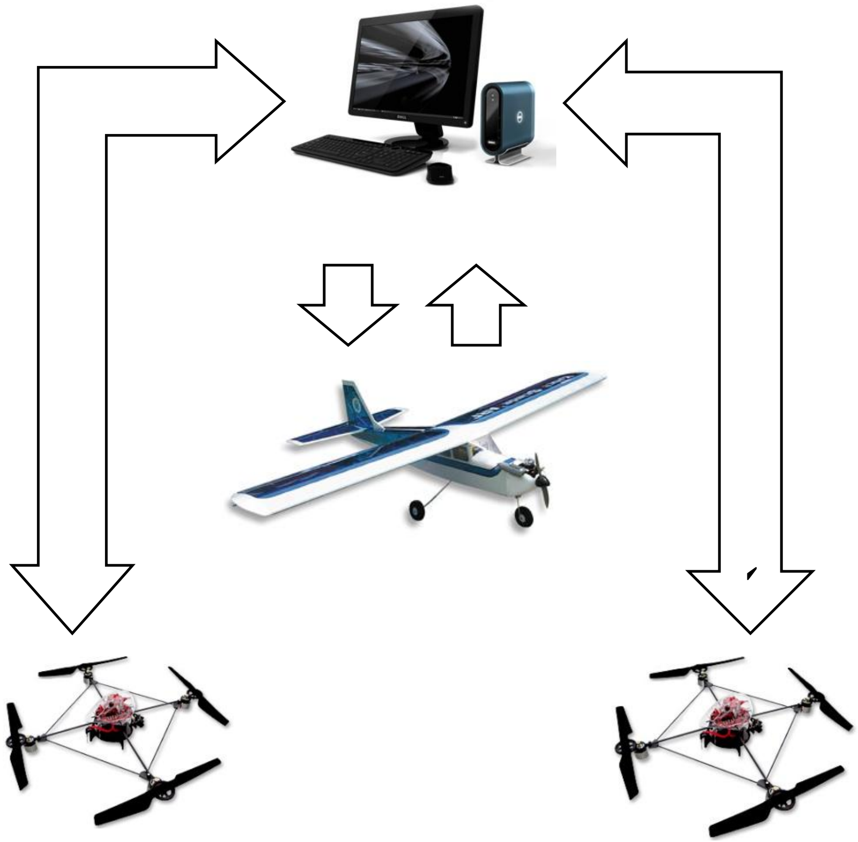
Scout & Base Rovers meet finally at the danger spot

AERIAL ROVERS – UAVs and Quad Rotors

Ground Control

Fixed wing UAV

Quad rotor UAV



UT Activities

Fixed air wing

RC airplane

Characteristics:
Wingspan 80 in
Wing Area 1180 in^2
Fuselage Length 64- 3/4 in
Flying Weight 6 - 6.5 lbs

Characteristics:
Wingspan 70 in
Wing Area 900 in^2
Fuselage Length 56 in
Flying Weight 5.5 lbs

Control board and sensors

Control board – Gumstix / Ciclone III
IMU – 3DM-GX2

GPS
Modem

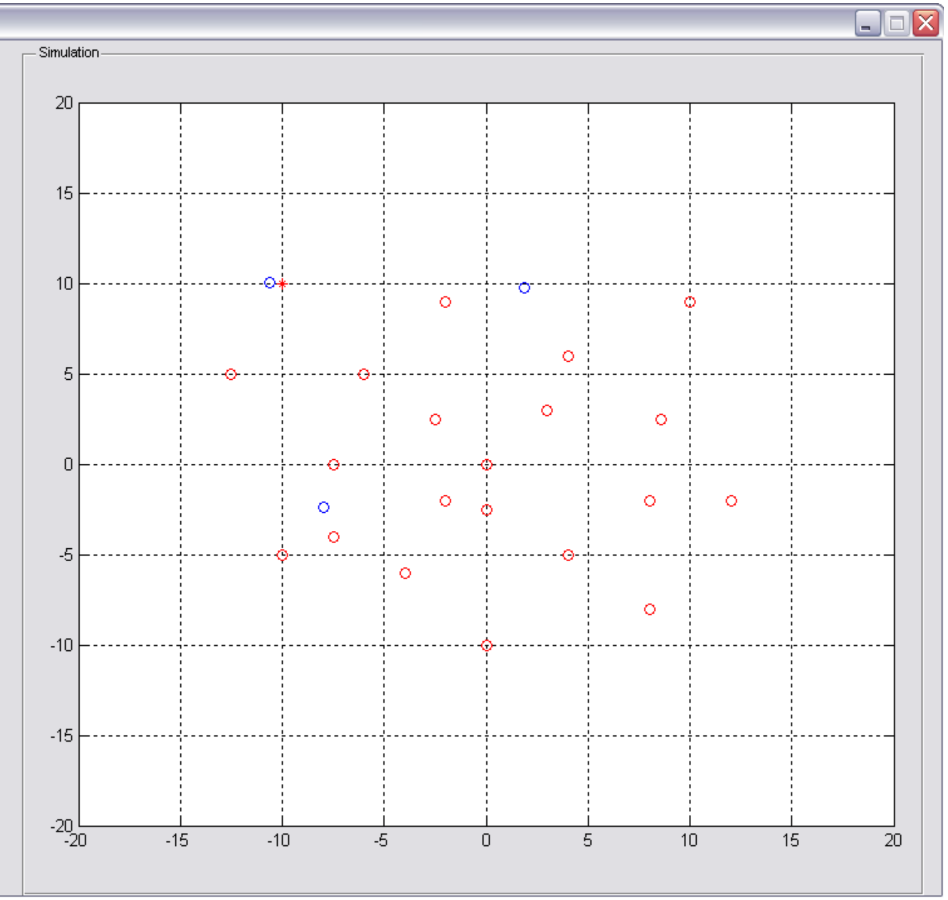
UTSA Activities

Fixed air wing

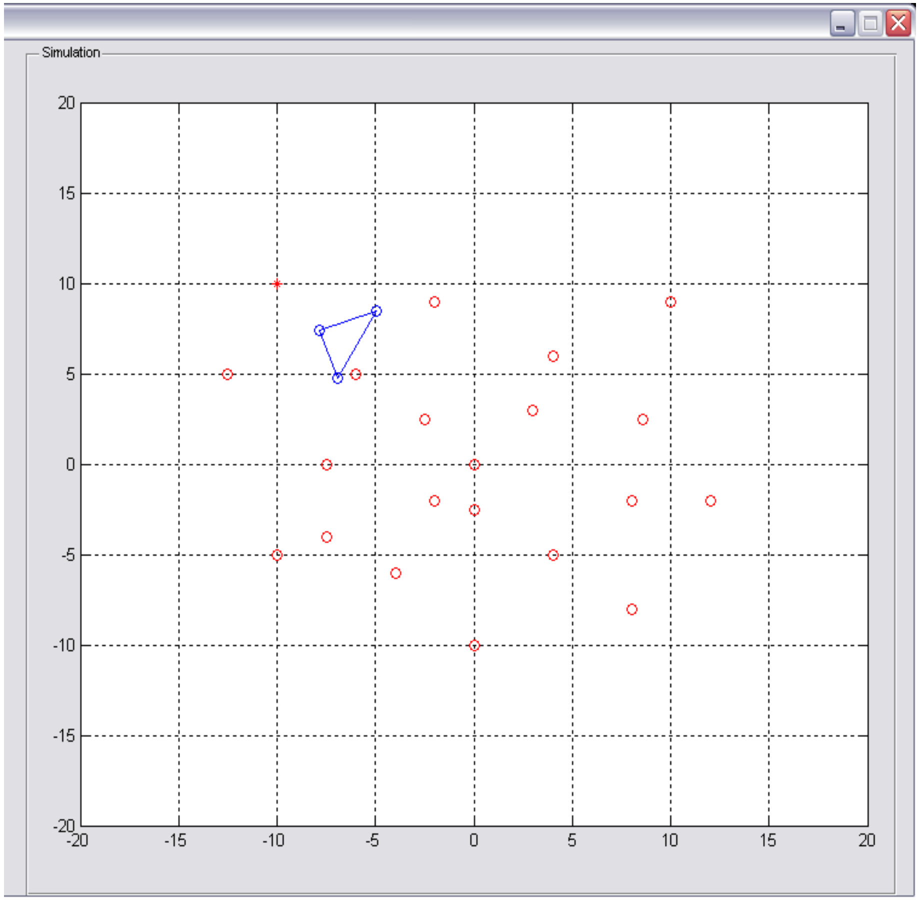
- **Main Objective** – Swarm of UAV
- **First objective – Autonomous flight**
- **Consensus Based Control of a UAV Formation**

ACE UAV on Runway

UAV Formation Simulation - 1



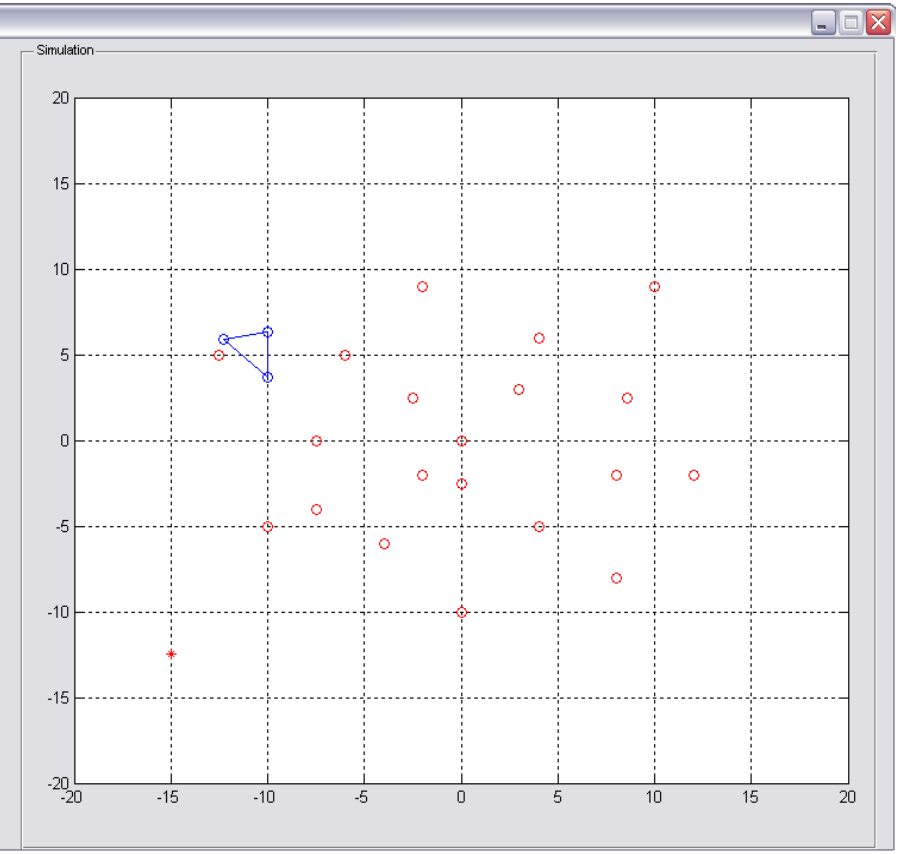
a



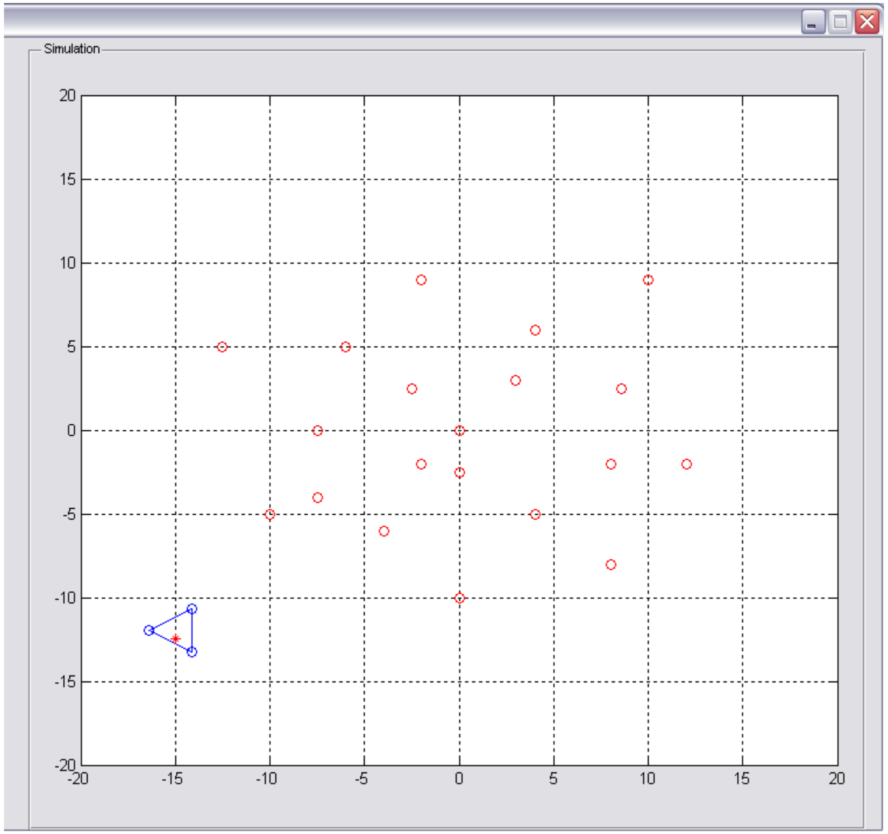
b

Consensus – Based Control **a**) UAVs approach each other **b**) Swarm goes to the first waypoint

UAV Formation Simulation - 2



c



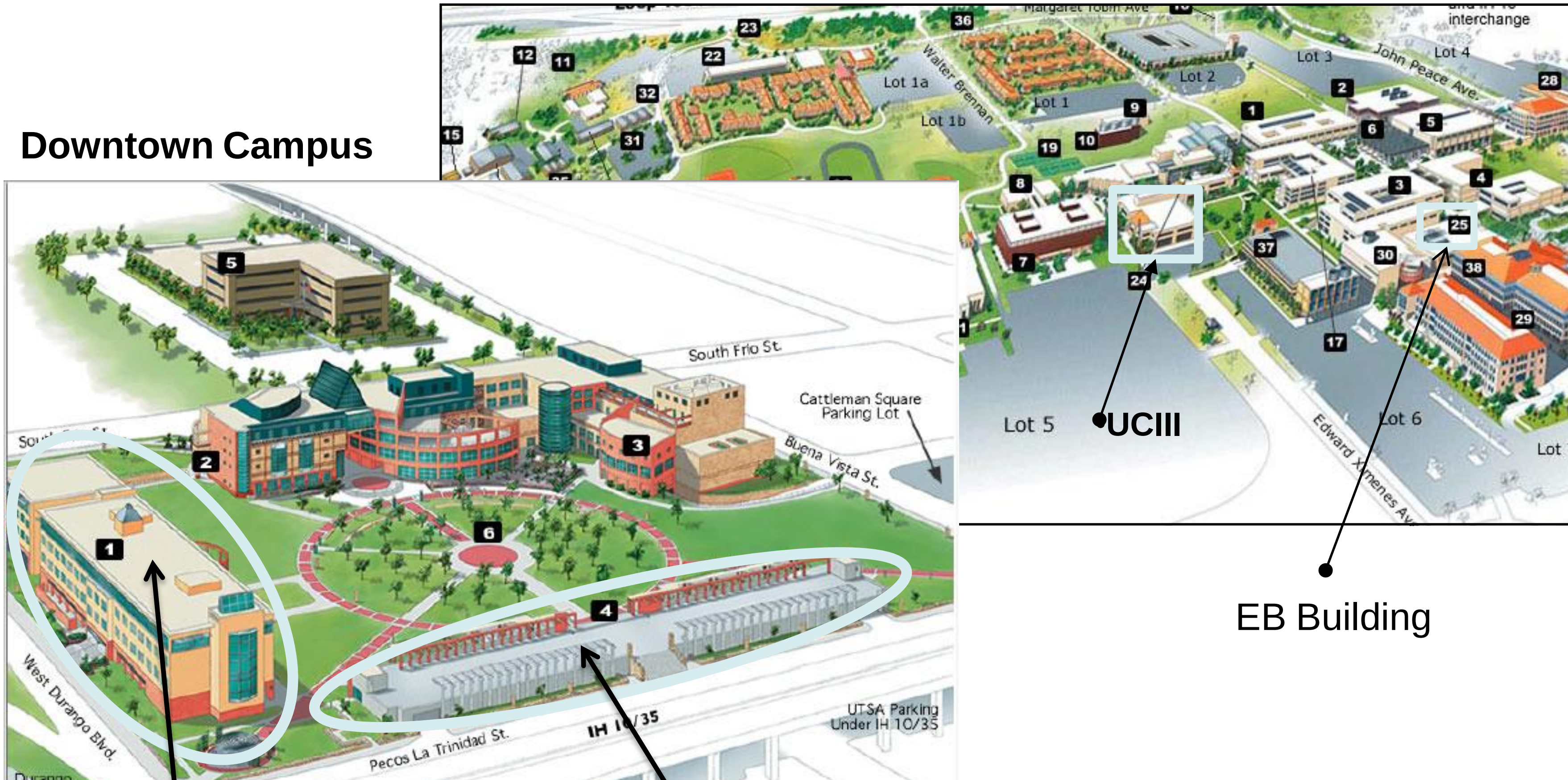
d

Consensus – Based Control **c**) Swarm leaves the first waypoint **d**) Swarm reaches the second point and gets ready to continue with the next waypoint

UTSA Smart Grid Project Distribute UTSA Sites - $ 2.4 ML

North Campus

Downtown Campus



•Durango Building

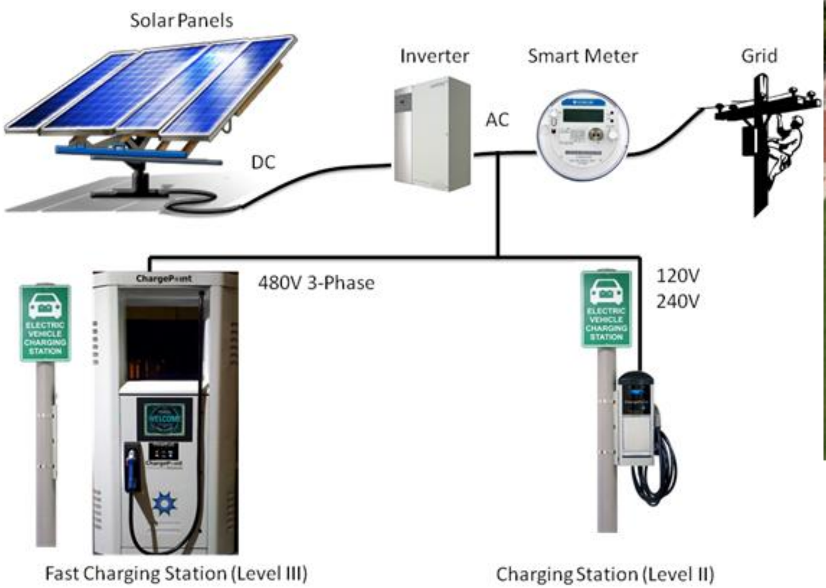
•Durango Parking Garage

SECO-2

Vehicle Electrification

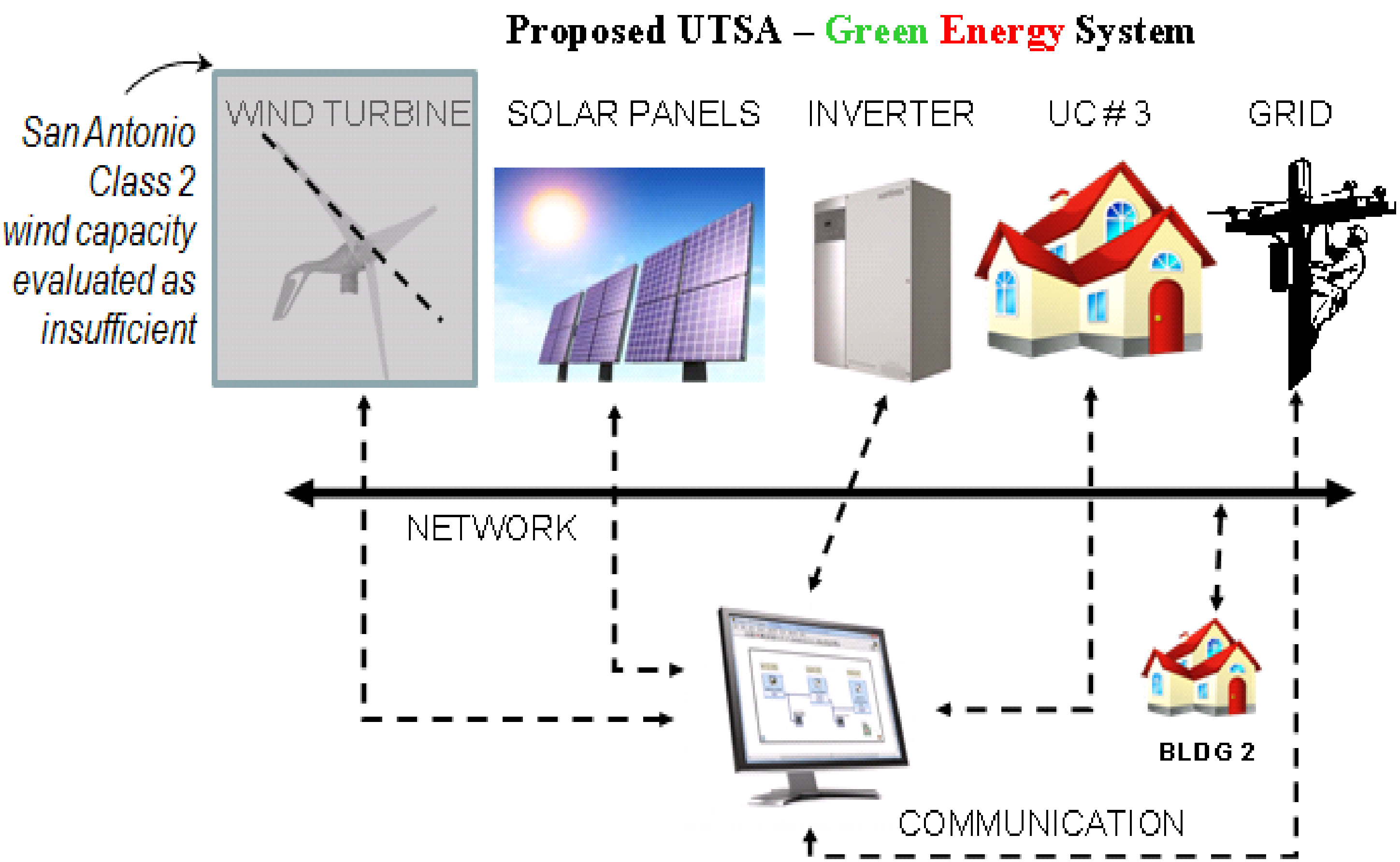
1 Level 3 Fast DC Charging Stations

1 Level 2 Charging Stations



Smart Technology

UCIII
Roof inspection
Thermal Plastic Polyolefin (TPO)



UCIII, SSB
Wireless sensor to Ethernet gateway Smart meter to utility (CPS)


TXSPC

Distributed, Secure Smart Grid Network

(One of the tasks with our team – 6 faculty and 12 graduate students)

Power Electronics Converter/Inverter

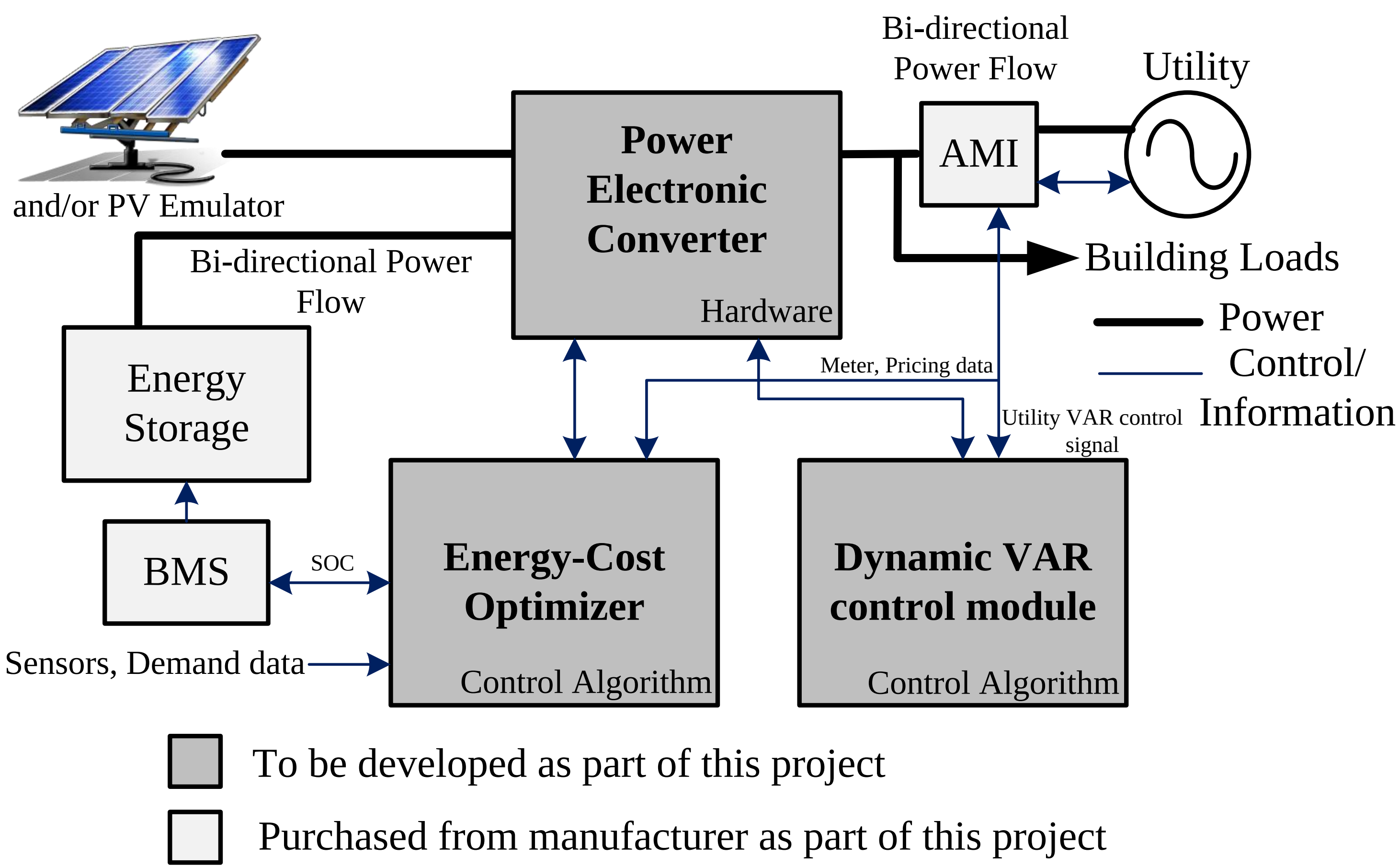
System Level Integration

Optimization of energy consumption for an individual building (CPS Energy Research Laboratory)

Energy Storage Technologies to be modeled and evaluated

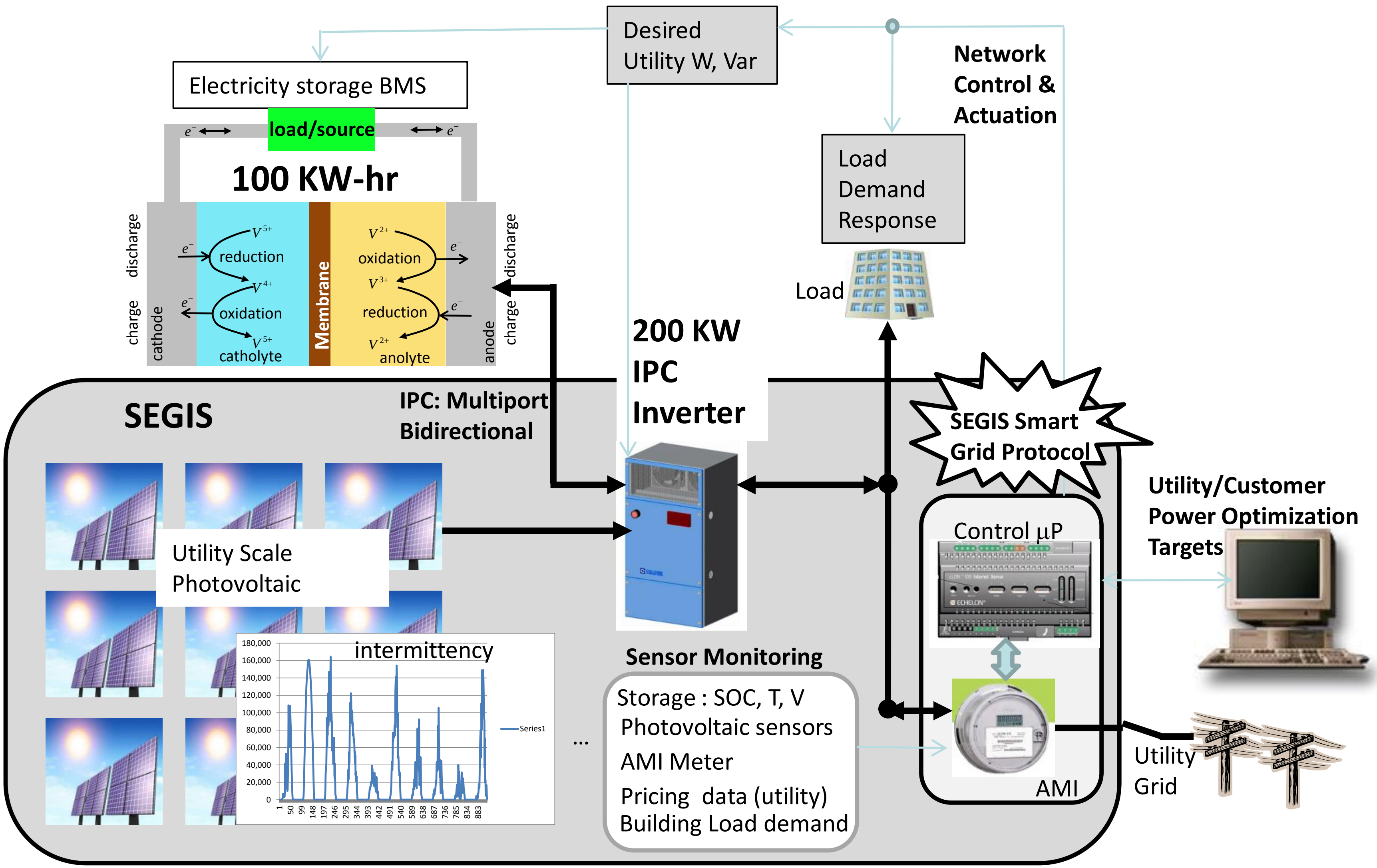
Cyber-security of the system

R&D Area 3



and/or PV Emulator
Bi-directional Power Flow
Power Electronic Converter
Hardware
Bi-directional Power Flow
AMI
Utility
Building Loads
Power
Control/ Information
Energy Storage
BMS
SOC
Energy-Cost Optimizer
Control Algorithm
Meter, Pricing data
Utility VAR control signal
Dynamic VAR control module
Control Algorithm
Sensors, Demand data
To be developed as part of this project
Purchased from manufacturer as part of this project

Proposal Smart Grid Demonstration Model w/CPS



Sun Edison Utility Scale Demonstration

consert
COMMUNICATE · CONTROL · CONSERVE
R Portal
CUSTOMER
UTILITY
SUPPORT CENTER
MANAGE INTERRUPTIBLE LOAD - CURRENT SNAPSHOT
Power Available
# of Gateways
Power Removed
EVENT ID
EVENT TYPE
USER ID
DURATION
START TIME
Consert solves challenges beyond AMI
Energy & Capacity
Renewables Compliance
Transmission & Distribution
Supplementary Services
Load Management
Spinning Reserves
Measurable
Verifiable
Congestion
Line Loss
PHEV
Wind & Solar
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SAMSUNG

Plug-In Electric Vehicle Coordination with Distributed Solar Photovoltaic Arrays: Theory and Application

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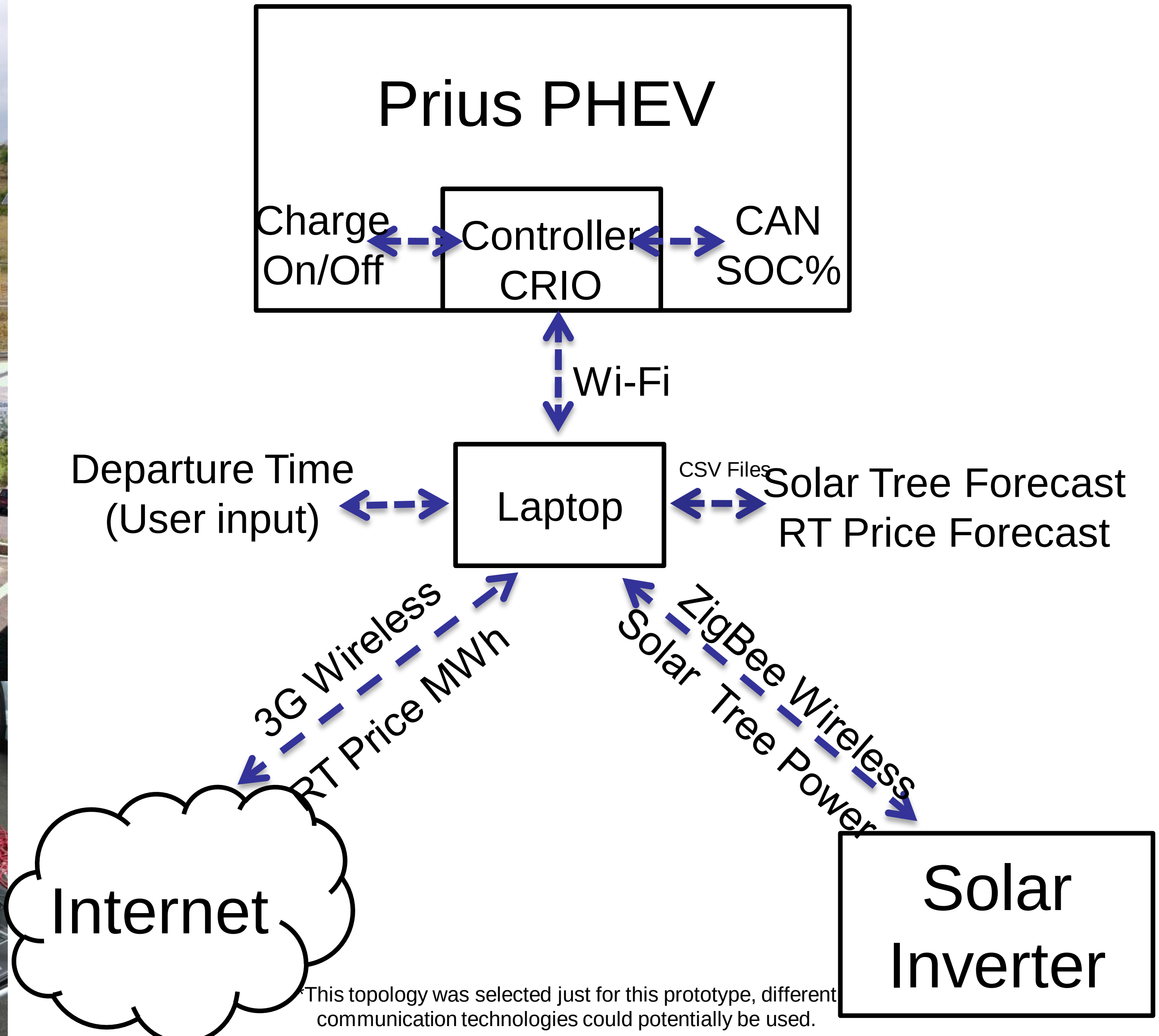
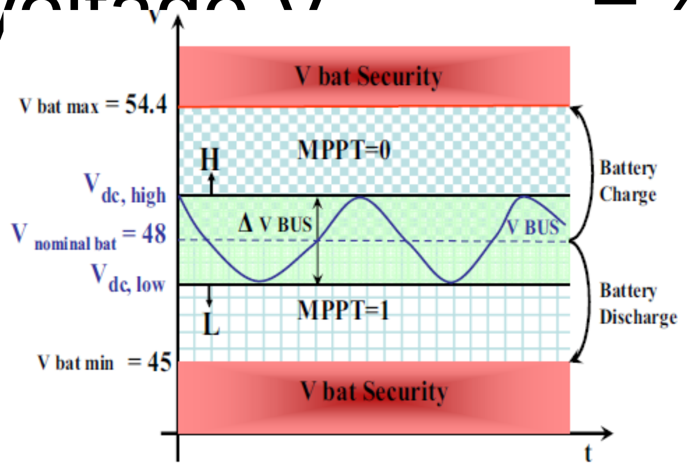
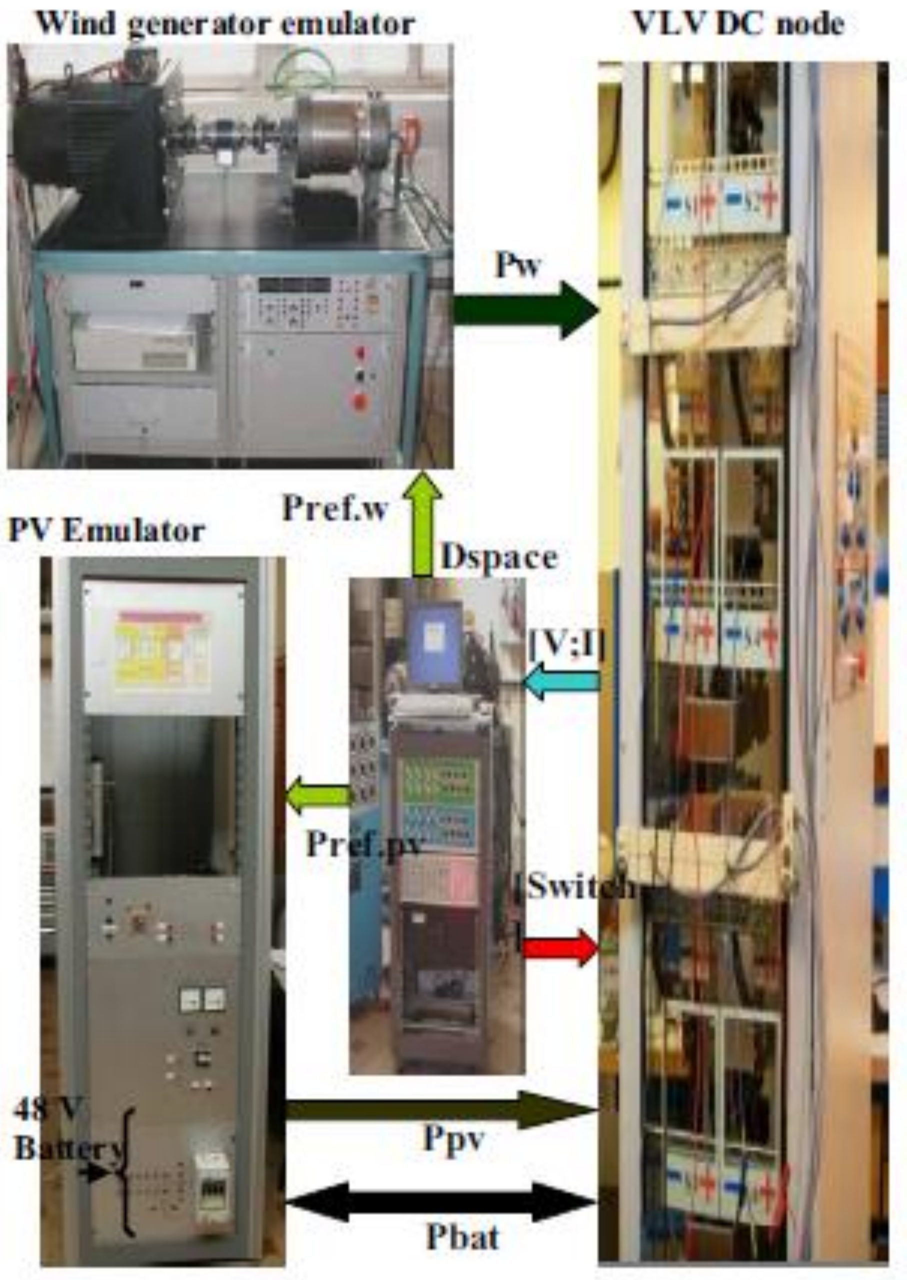
Proposed System Topology



*This topology was selected just for this prototype, different communication technologies could potentially be used.

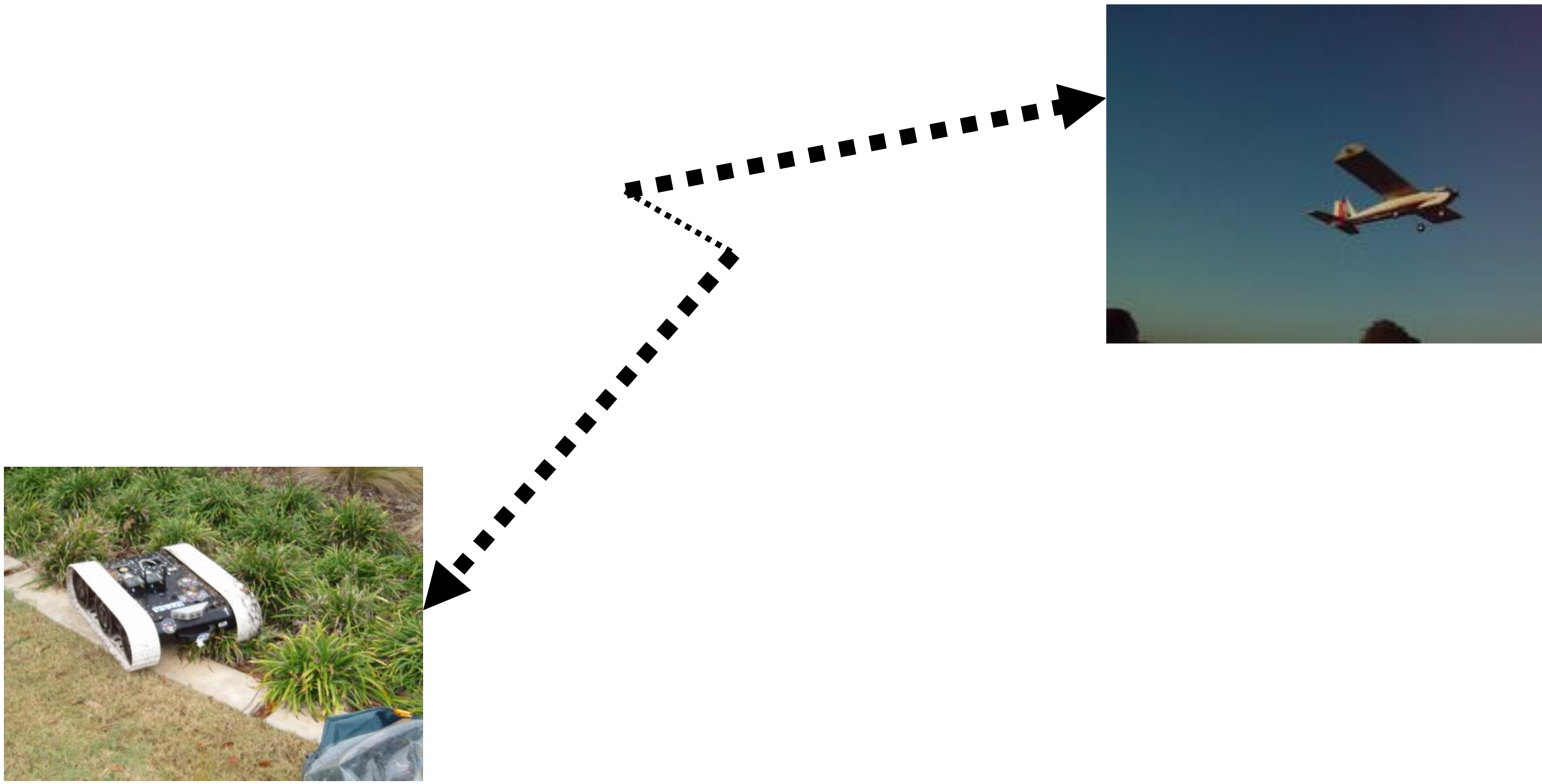
- The utility of energy management supervisor to control the battery SC by keeping the DC bus voltage , between two imposed limits(54 V , 43 around the rated battery voltage V = 48 V.



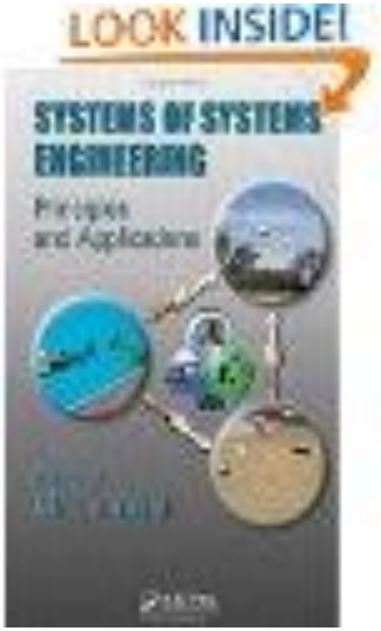


ACE UAV – Land Rover SoS

UT Activities



Amazon.com



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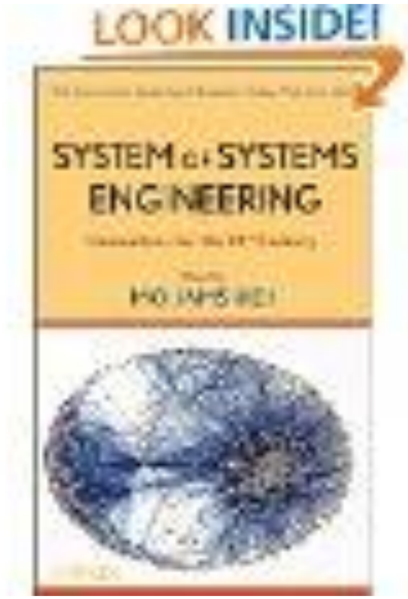

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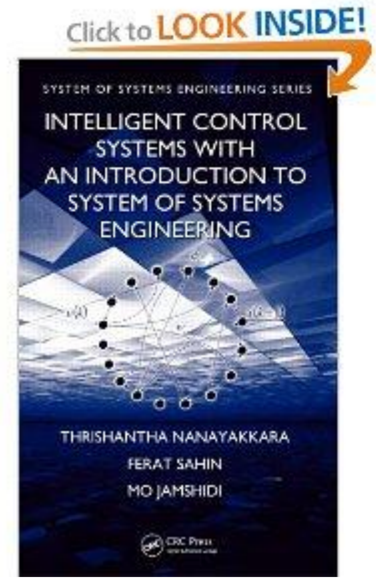

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CONCLUSIONS

SoS has been with us for some time

Soon … System integration will be a matter of necessity and not Choice

Application potentials are too numerous to be ignored by any scientist/engineer. While … Theoretical challenges are numerous as well.

These challenges will bring about numerous IP's and patents.

Control, DSP, modeling, simulation, … and Artificial Intelligence communities can help in many areas of SoS and pave the way for realization of many potential IP's.

Once again, Systems Engineering is a discipline, while SoS Engineering is an "opportunity".

Movie clips

QUESTIONS

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