Machine Learning for Remote Tactile Internet Robotic Surgery

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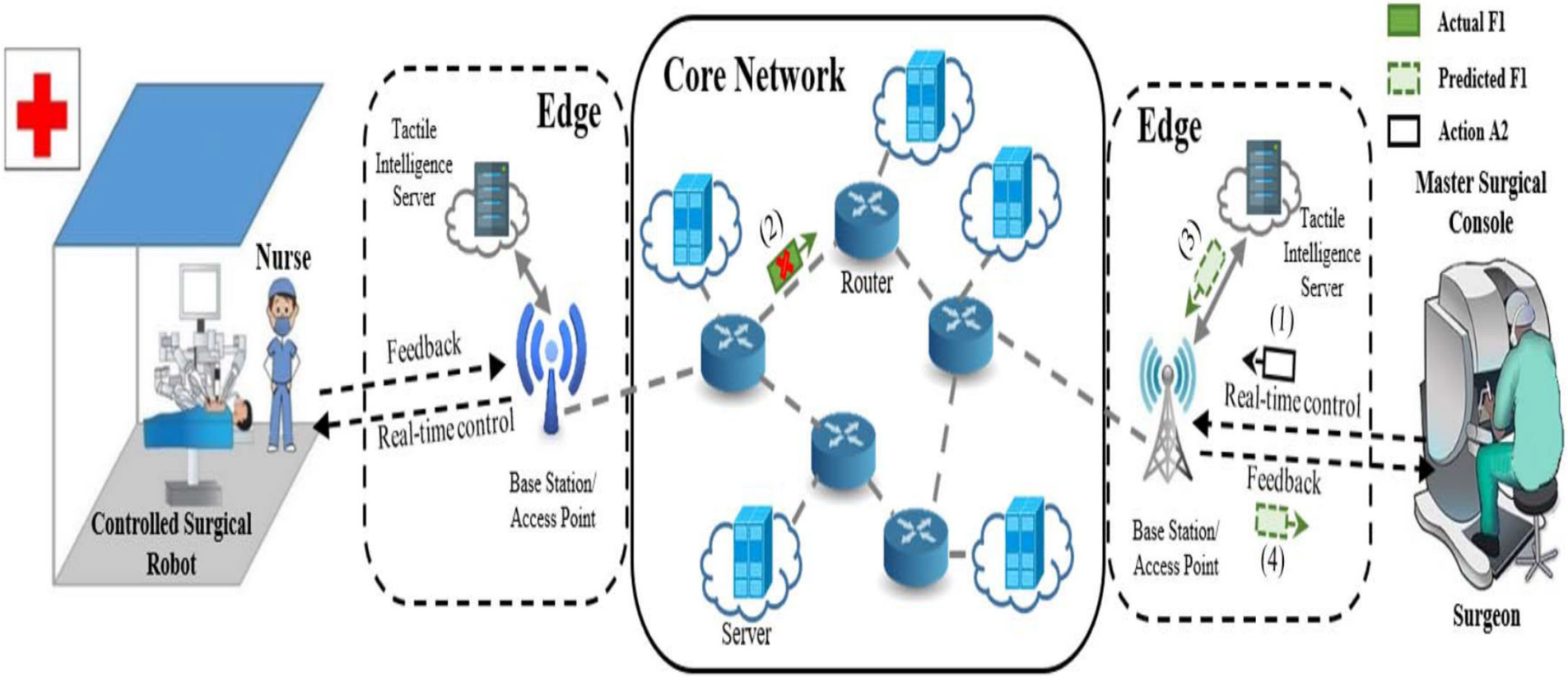
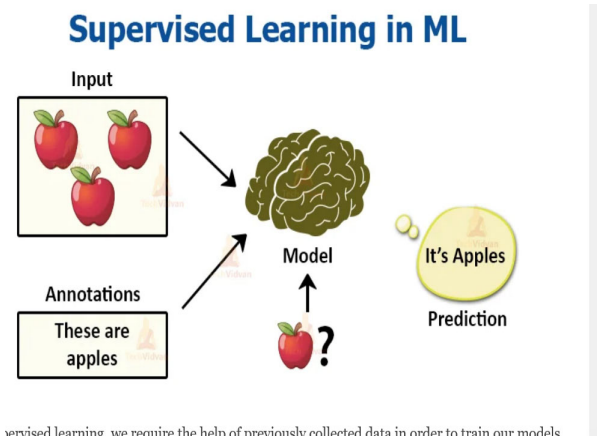
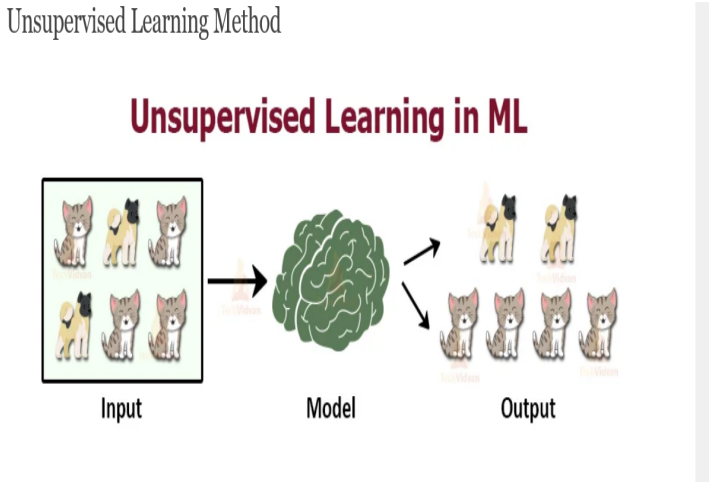
Where We Are Today
(Surgeon and patient in a same room)

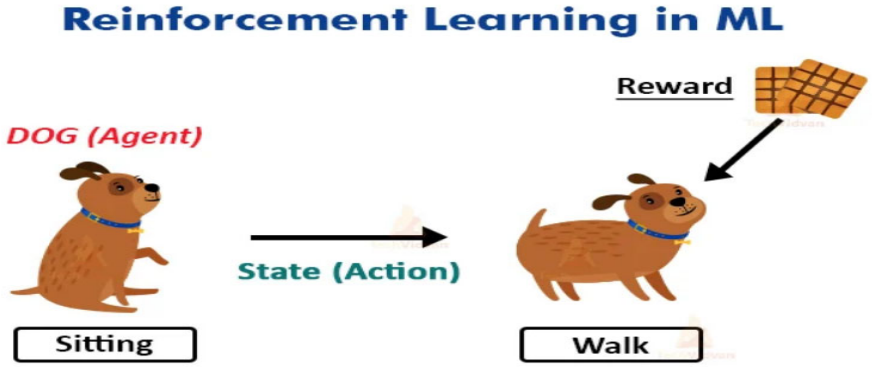
Where We Wish to Be Tomorrow (Surgeon and Patient Remotely Located)



Key Enabler (Machine Learning)







https://techvidvan.com/tutorials/types-of-machine-learning/

Presentation map

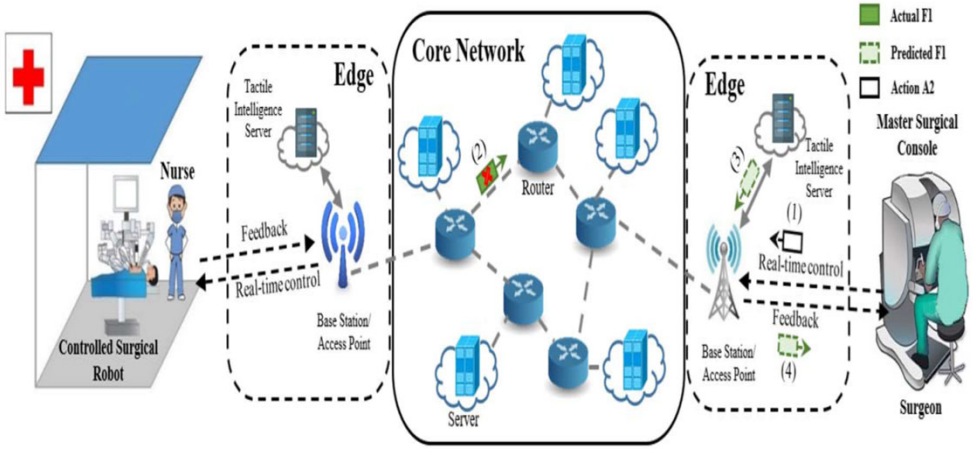
- **Remote Tactile Internet Robotic Surgery**
  - Robotic surgery
  - Remote robotic surgery and challenges

- **Machine Learning for Remote Tactile Internet Robotic Surgery**
  - Machine Learning Basics
  - Use Cases
    - Predicting delayed / lost packets
    - Predicting packets that will be lost

Outline

- Remote Tactile Internet Robotic Surgery and its Challenges
- Machine Learning for Tackling the Remote Robotic

Remote Tactile Internet Robotic Surgery and the Challenges …



On Robotic Surgery

What is It?

- Got very popular with Da Vinci robot in the early 2000s

✓ **Expert surgeon**

✓**Surgeon console**

- Stereoscopic/immersive view of the patient inside
- Hand manipulators and foot pedals to control the robot arms

✓**Robot**

- Fully controlled by the surgeon (No autonomy) – Robotic assisted surgery
  - Arms
    - Surgical instruments …

What is It?

- **Used in all phases of surgery**
  - ✓Access to the body cavity
  - ✓ Tissue dissection
  - ✓Tissue reconstruction

What is It?

- **Applicable to almost any surgery today**
  - ✓ Urology
  - ✓Heart
  - ✓Appendectomy
  - ✓ etc

Why?

- ✓More precision
- ✓Immersive view for the surgeon

- ✓**Several benefits for the patient**
  - ➢ Less blood loss
  - ➢Less pain
  - ➢ Much speedier recovery time

What are the key issues?

✓ Cost

- Capex: Purchase: 2 – 5 Million USD

- Opex: Instruments to change after each surgery
- Training of expert surgeons

- Training of expert surgeons

What are the key issues?

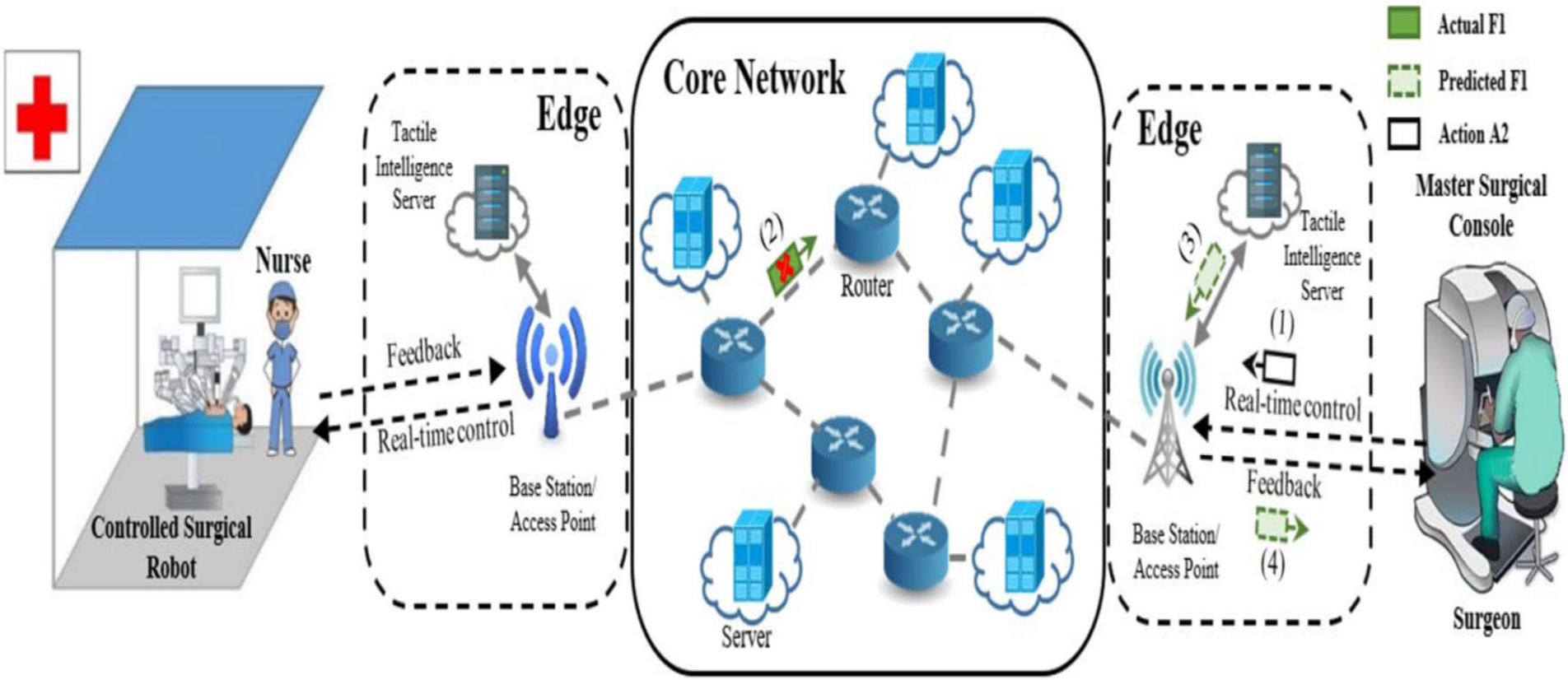
- **Limited access**

  ✓ Few deployments in
  - small cities
  - Rural areas
  - Developing countries

The Situation in Africa

- **Egypt (Very first)**
- **South Africa (A few …)**
  - ✓ e.g. Cape Town
    - Recent deployment in a public hospital – 2022
    - "Celebration" of the very first female robotic surgeon in South Africa (Farzana Cassim)

On Remote Robotic Surgery



What is It?

Surgeon and patient far from each other

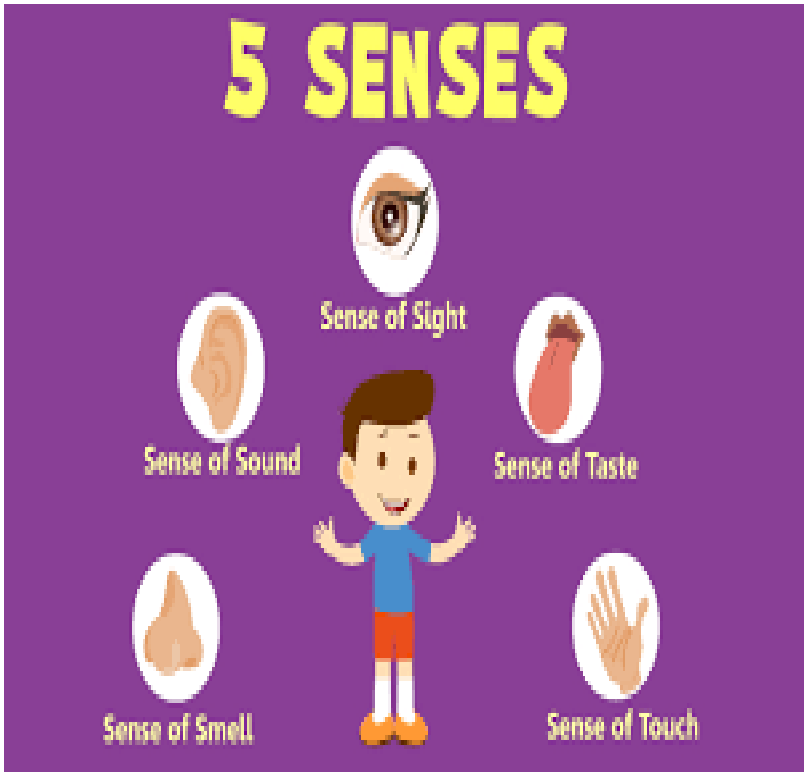
- ✓ **Expert surgeon**
- ✓**Surgeon console**
- ✓ **Network**
  - 5G / 6G

What is It?

It is actually an example of a wider range of applications known as Tactile Internet Application

On Tactile Internet

- ✓ A baby step towards the Internet of the Senses foreseen for 6G (Focus: Touch)



On The Tactile Internet

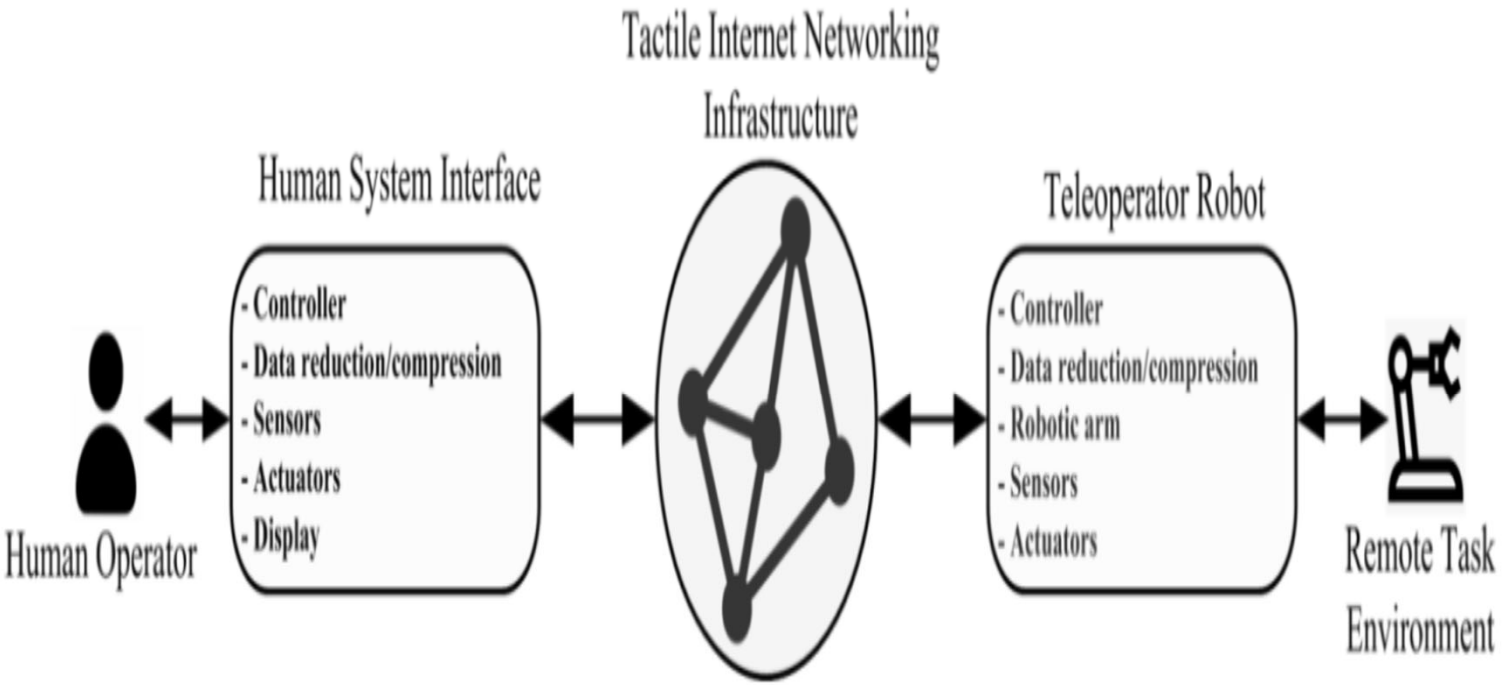
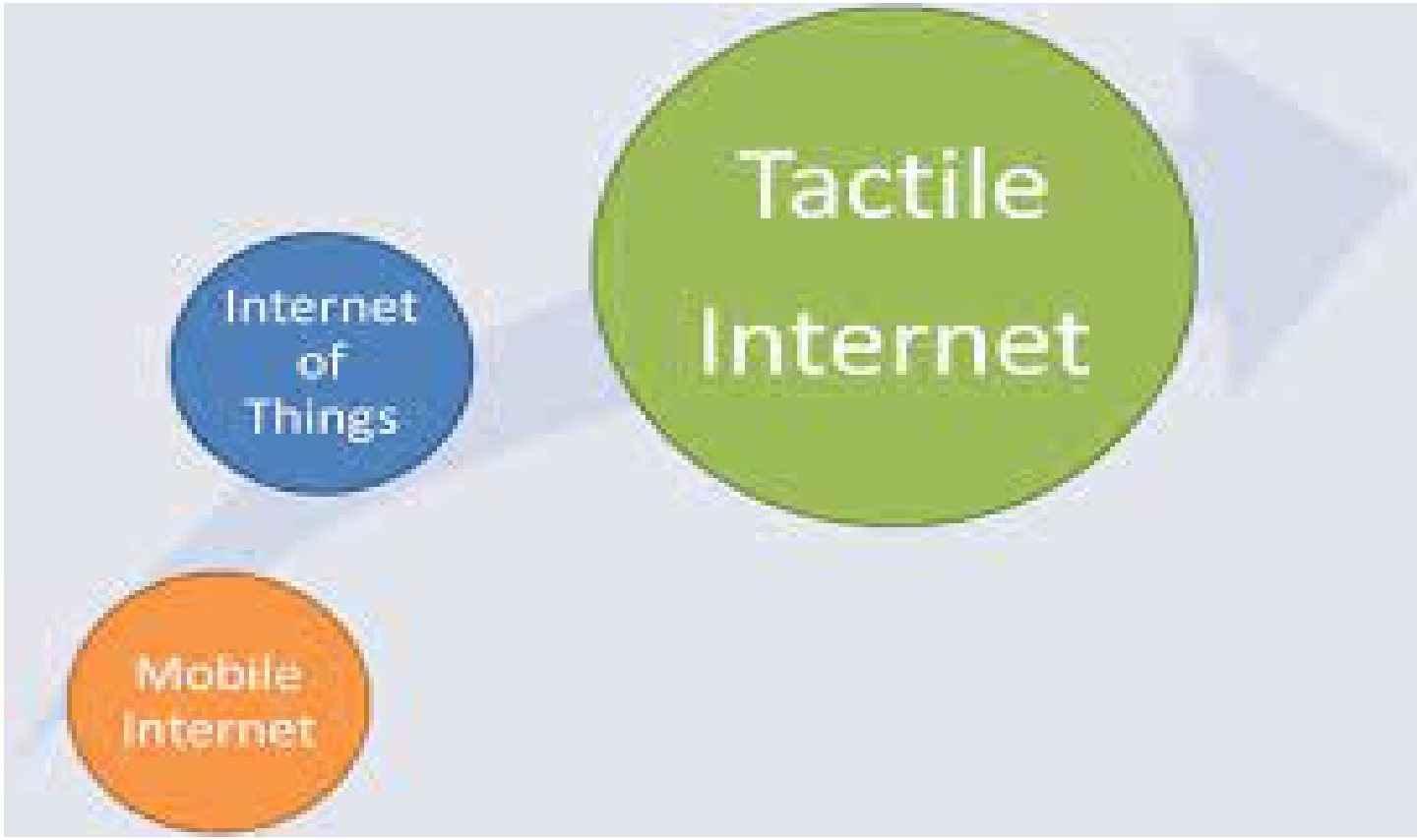


Fig. 4: Teleoperation system based on bidirectional haptic communications between a human operator and a teleoperator robot.

On Tactile Internet

- ✓ A natural evolution of the Internet



On Tactile Internet

✓ A natural evolution of the Internet

- Haptic communications over networks in addition to data/audio/video
  - Haptic communications:
    - ➢ Transmission of Cutaneous and kinesthetic feedback

On Tactile Internet

- ✓ **A very powerful concept -**
  - Skills delivery over networks (e.g. remote robotic surgery, remote repair)
  - Emotion/feeling/Sensation delivery over networks (e.g. remote “hugs”)

Why Tactile Remote Robotic Surgery?

- ✓**Transfer of skills over networks**
  - Surgeon in a capital city operating on a patient in a rural area
  - Surgeon in a developed country operating on a patient in a developing country

What are the challenges of Tactile Remote Robotic Surgery?

- ✓ **Pretty easy to guess -**
  - Computational challenges
  - Communication challenges
    - ➢ Ultra low latency
      - » 1ms RTT for remote robotic surgery
    - ➢ Ultra high reliability

What are the challenges of Tactile Remote Robotic Surgery?

- ✓ **A bit less easy to guess -**
  - Intelligence challenges
    - ➢ What if the packet does not reach in time in remote surgery session?
      - » **Haptic message lost/delayed?**
      - » **Haptic feedback lost/delayed?**

Tactile Remote Robotic Surgery today (Done over a 5G Network)

5G and remote robotic surgery

(World first 5G remote robotic surgery – early 2019)

http://en.people.cn/n3/2019/0115/c90000-9537898.html

Tactile Remote Robotic Surgery today (Done over a 5G Network)

5G and remote robotic surgery

(World first 5G remote robotic surgery – early 2019)

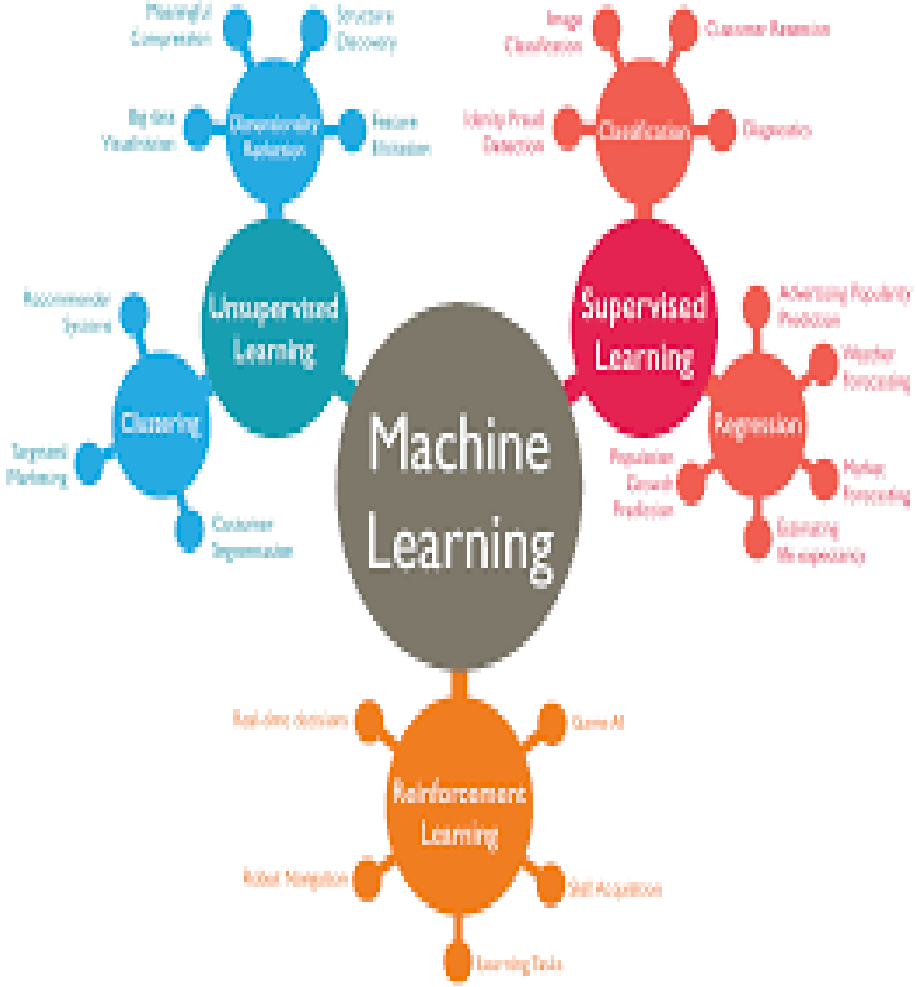
However, it was on pig …

There are now simple remote robotic surgery on humans (e.g. orthopedic surgeries)

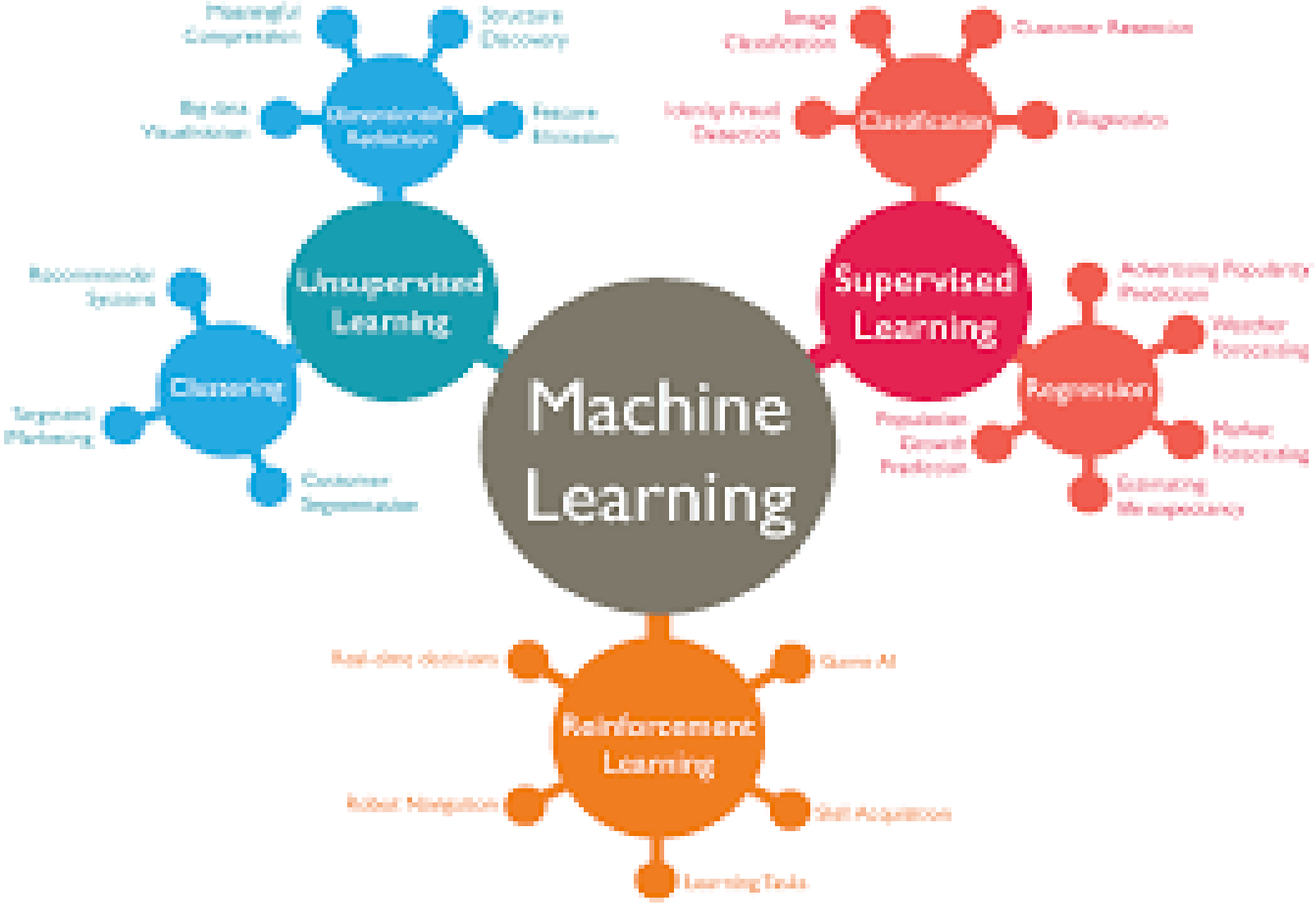
https://www.tellerreport.com/business/2021-03-04-%0A---the-first-domestic-5g-remote-orthopedic-robot-assisted-trauma-surgery-completed%0A--.SyBgxr-AG_.html

There is no intelligence component and procedures are rather restricted (e.g orthopedic surgeries)

Machine Learning for Remote Tactile Internet Robotic Surgery …



On Machine Learning



What is It?

“ Bring to systems the ability the ability to actively learn and improve their behavior without the need to be programmed”

- Learning process
  - Study input to detect patterns or regularities

What Is It?

An example: Knot tying trajectory in surgery

- Set of knot tying trajectories performed by several surgeons
- Mathematical model
  - Examples of factors: angle velocity, rotational velocity
- Prediction of the next surgeme (gesture) based on the current state of the system
  - Comes in very handy for predicting a lost haptic message

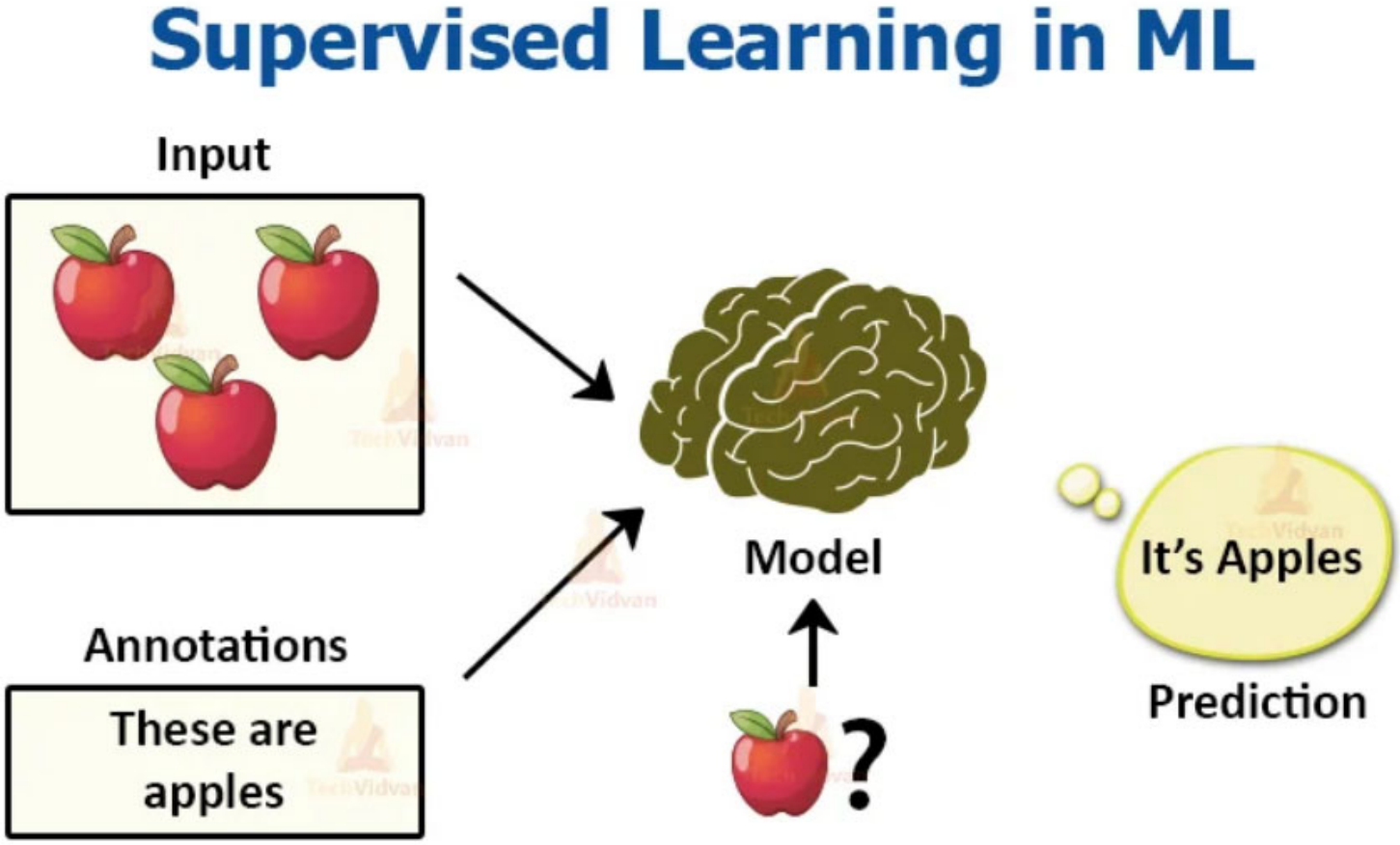
How is it done?

Some examples:

https://techvidvan.com/tutorials/types-of-machine-learning/

How is it done?

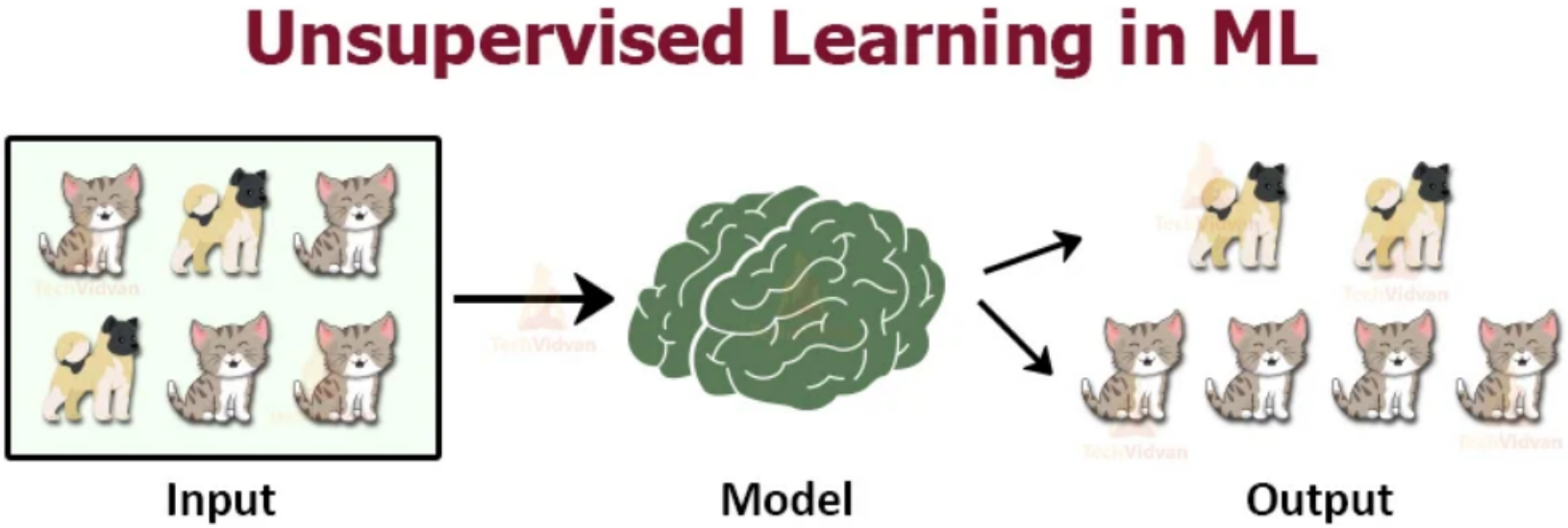
Some examples (e.g. SVM, KNN ….)



How is it done?

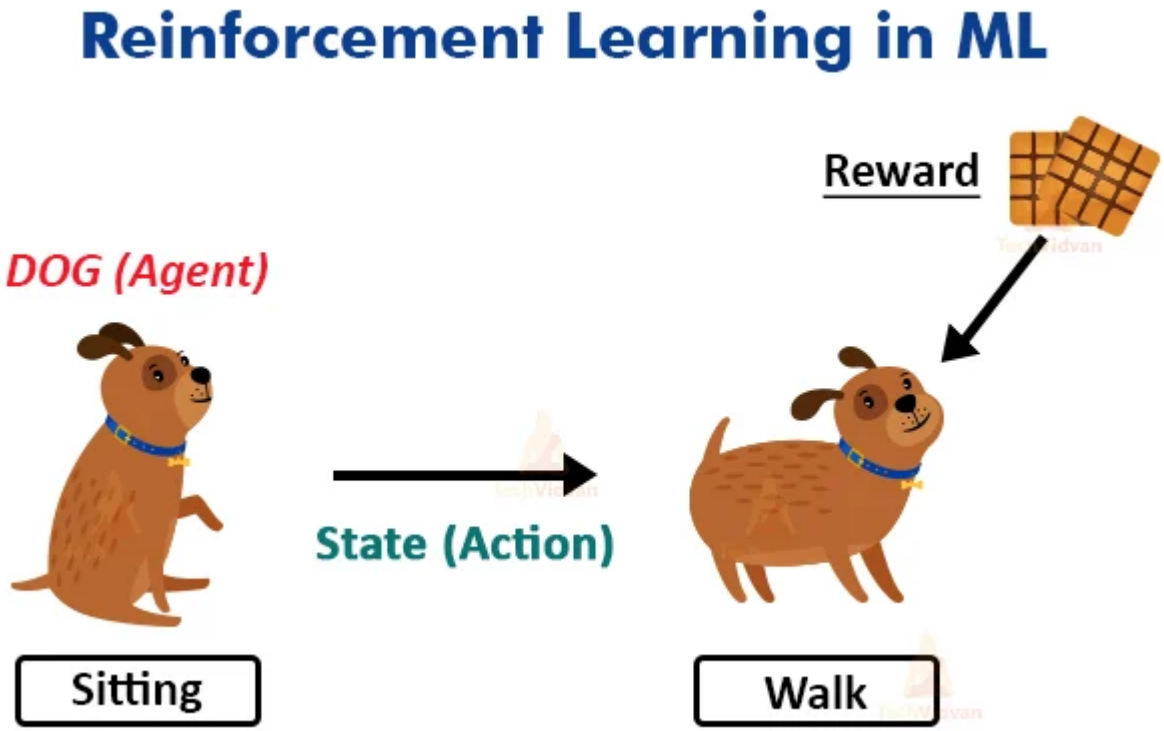
Some examples (K-Means)

Unsupervised Learning Method



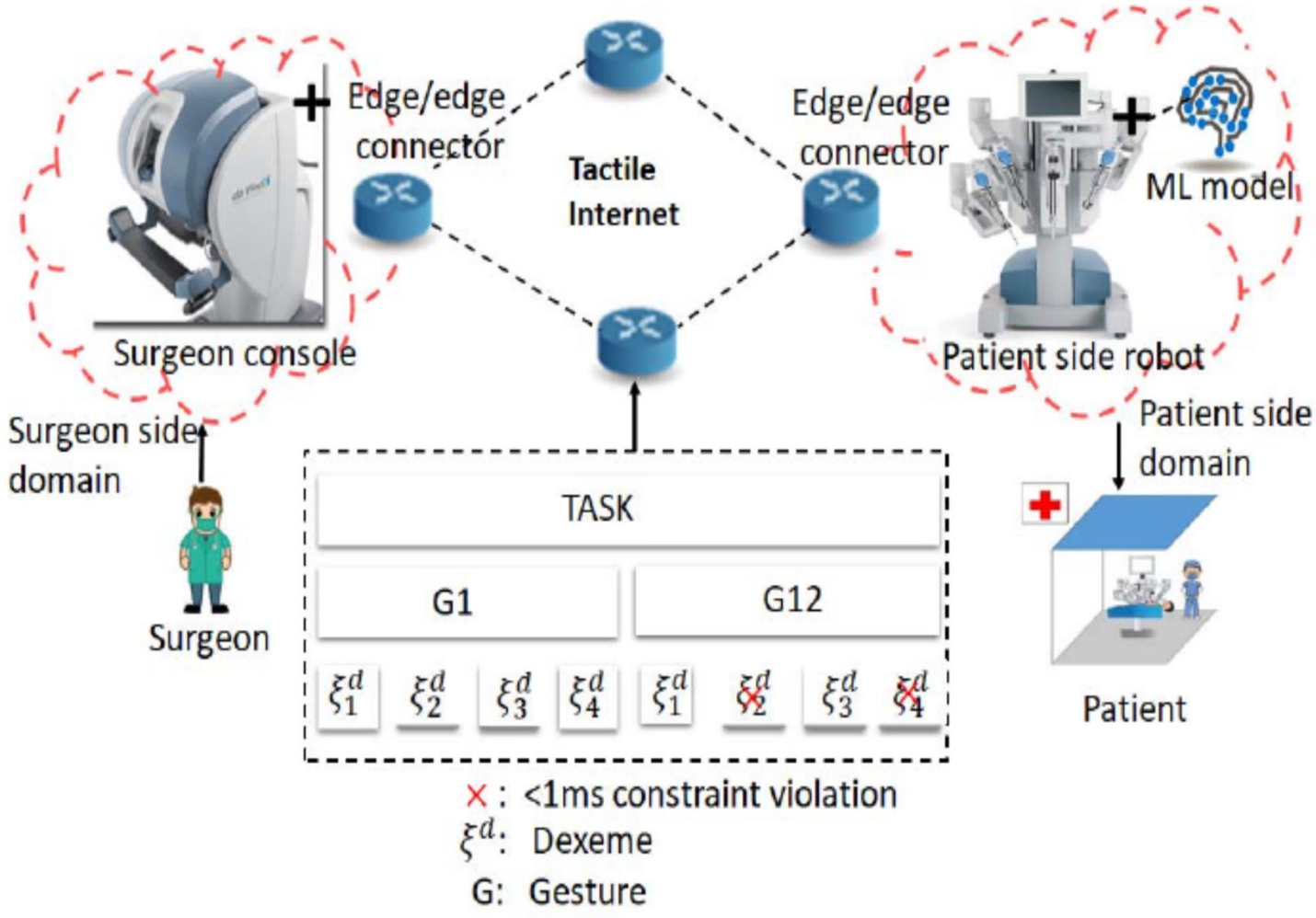
How is it done?

Some examples



Machine Learning for Remote Tactile Internet Robotic Surgery …

The Problem


Edge/edge connector
Tactile Internet
Edge/edge connector
ML model
Surgeon console
Patient side robot
Surgeon side domain
Patient side domain
TASK
G1
G12
Surgeon
Patient
× : <1ms constraint violation
ξ^d: Dexeme
G: Gesture

The Problem

TABLE II
KNOT TYING GESTURE VOCABULARY [21]

Gesture Index	Gesture Description
Ω1	The surgeon picks up needle with right hand
Ω12	The surgeon picks up needle with left hand
Ω13	The surgeon makes a C loop around right hand
Ω14	The surgeon picks up suture with right hand
Ω15	The surgeon pulls suture with both hands to tie a knot

The Problem

- ✓ **What happens if any of these messages does not reach in time?**

- ✓ **The requirements are very stringent**
  - Ultra-low latency (1-10~ms) . ML techniques with fast prediction times are needed to achieve ultra-low latency communications.

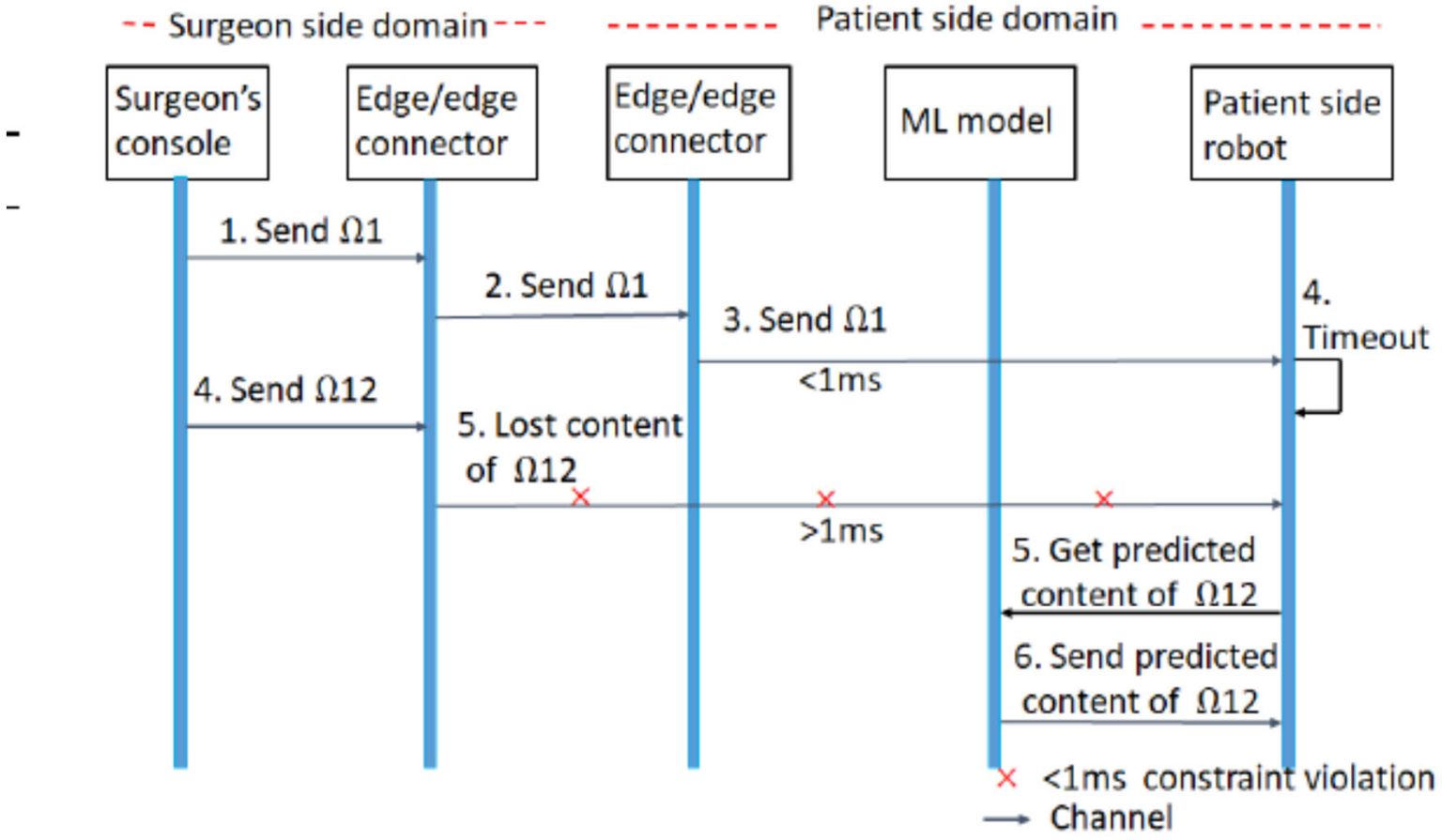
  - Ultra-high reliability (99.999%). A machine learning scheme with fine-tuning capabilities is required to prevent over-fitting the limited datasets and run accurate predictions.

The Potential solutions

- ✓ In reactive prediction, the predictor reacts when a packet does not reach within the set time by predicting its content.

- ✓ In proactive approach, predictor first predict packets that might get lost/delayed and then proactively predict their content before the delay/loss happens.

Reactive approach



Reactive approach

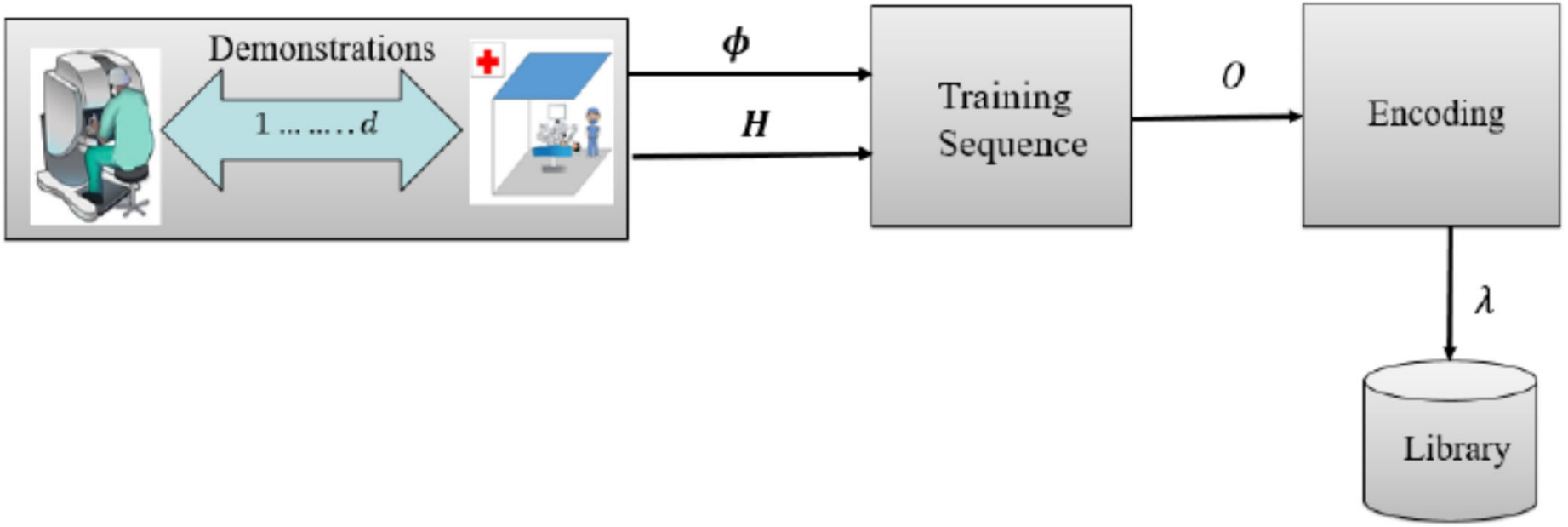


Fig. 2. Training dataflow

Reactive approach

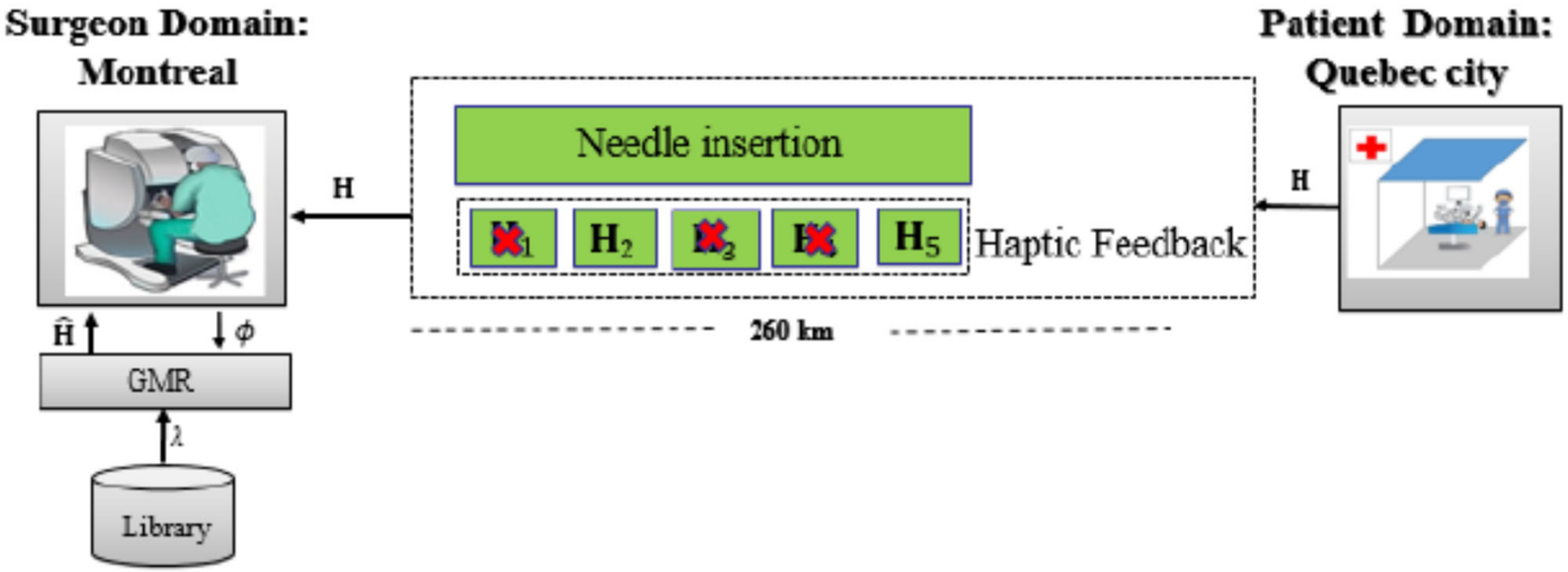


Fig. 3. On-line retrieval dataflow

Reactive approach

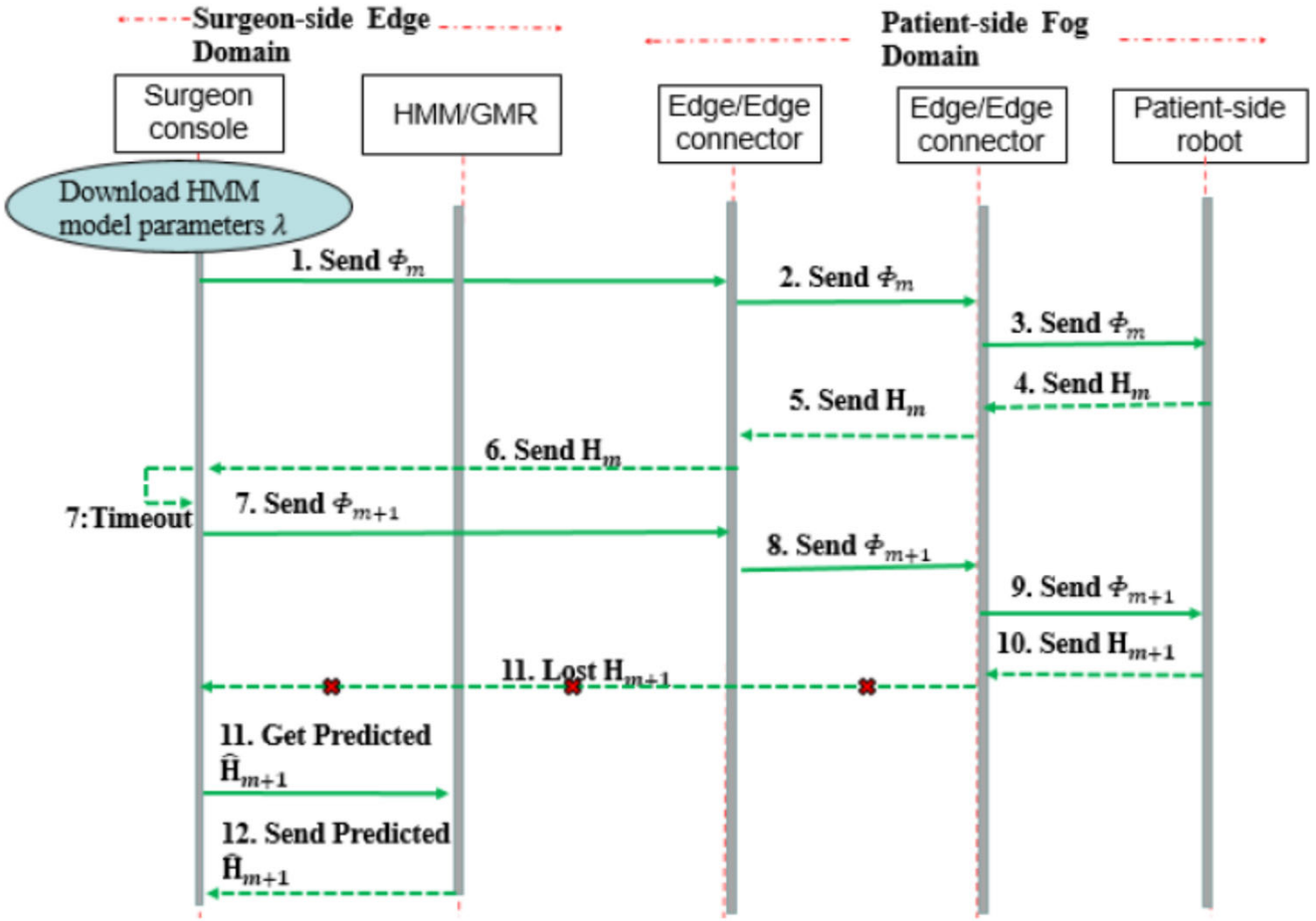
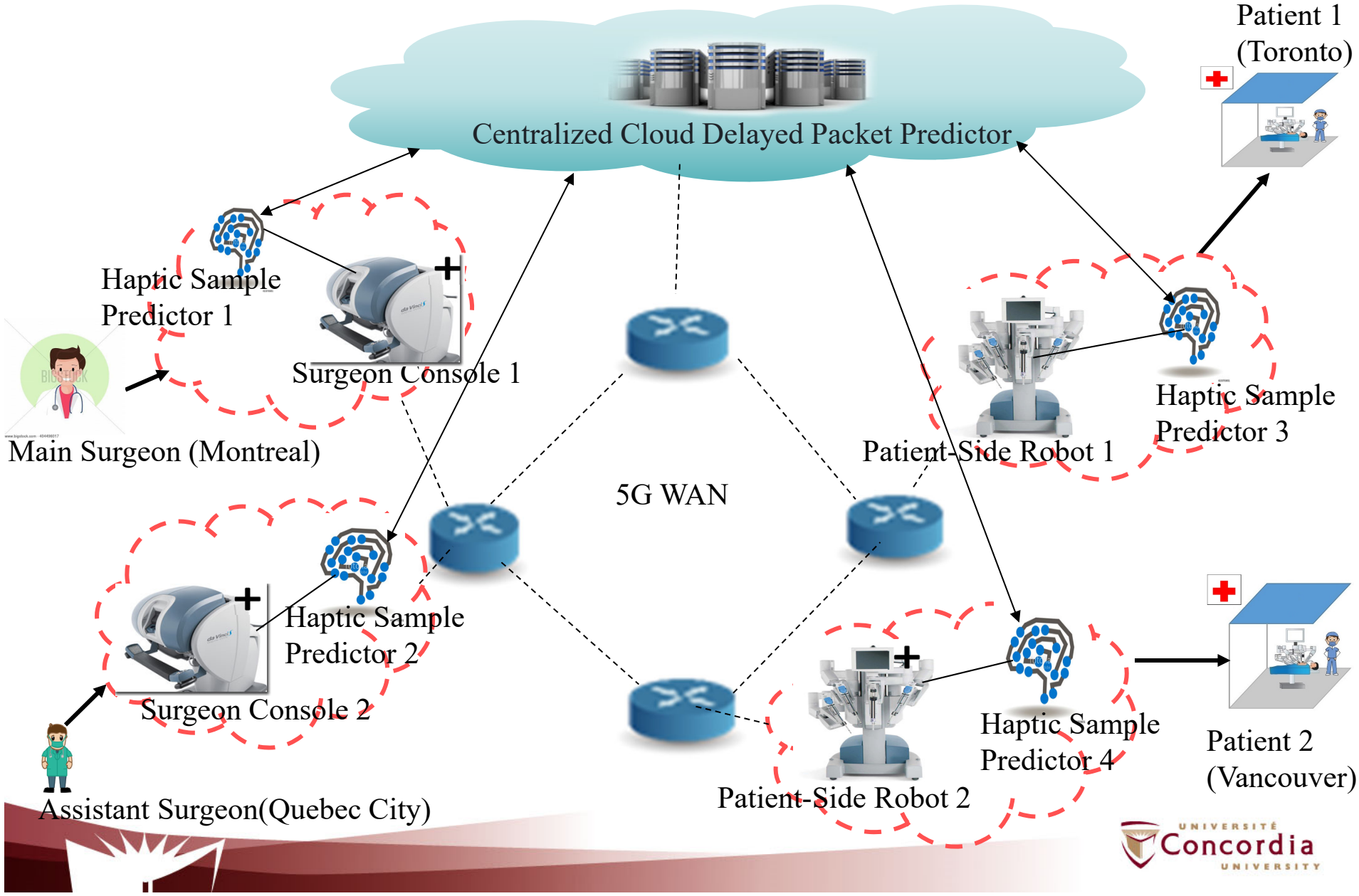
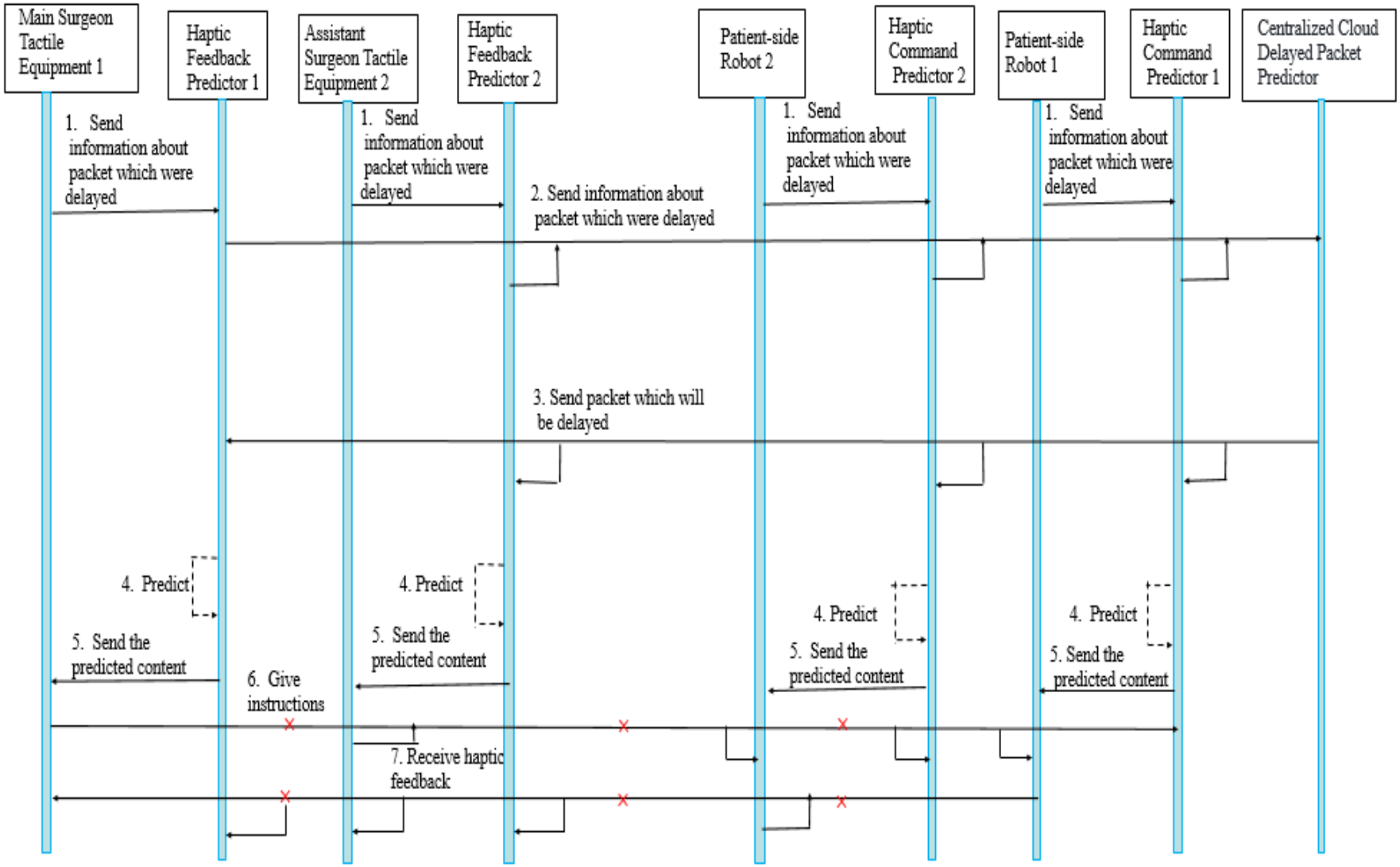


Fig. 4. Sequence of operations

Proactive Approach: Centralized Learning



Proactive Approach: Centralized Learning



Conclusions

Robotic surgery is here to stay because of the benefits to the patients and despite its cost (Capex, Opex, and training of expert surgeons)

Remote robotic surgery will certainly become somehow popular because of 6G and the progress in Machine learning

However, the robot will probably never fully replace the human surgeon

.

Selected References

F. Boabang; A. Ebrahimzadeh, R. Glitho, H. Elbiaze, M. Maier, F Belqasmi, A Machine Learning Framework for Handling Delayed/Lost Packets in Tactile Internet Remote Robotic Surgery, IEEE Transactions on Network and Service Management (TNSM), December 2021, Vol 18, Issue 4

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