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Physiologically-Aware Communication Architecture for Transmission of Biomedical Signals in BASNs for Emerging IoT Applications

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Abstract

This research work proposes a novel **physiologically-aware communication architecture** for the transmission of **biomedical signals** in BASNs (Body Area Sensor Networks) and wearables for emerging IoT applications. The architecture to fulfill the following objectives:

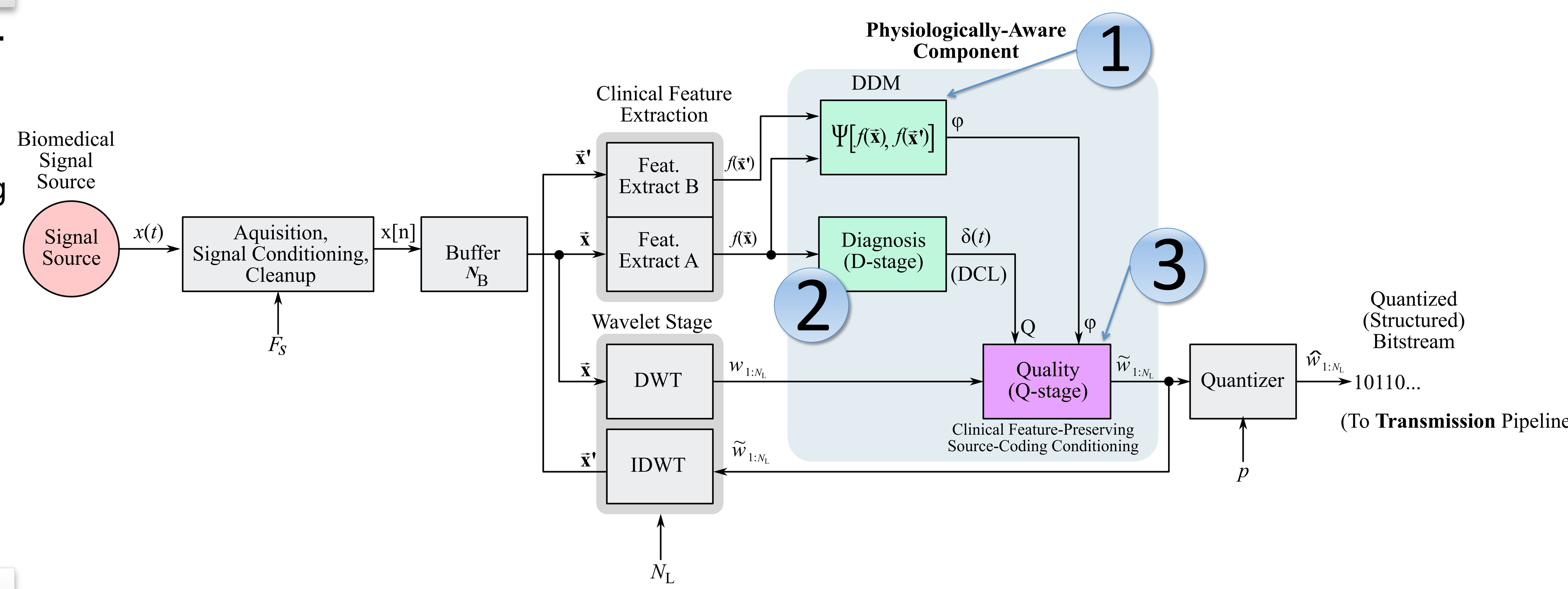
- Reduce volume of biomedical data in IoT networks and Internet infrastructure.
- Minimize the required computational load of biomedical data on the cloud side.
- Extend the lifetime of the mobile wearable/BASN through improved energy savings.

Architecture

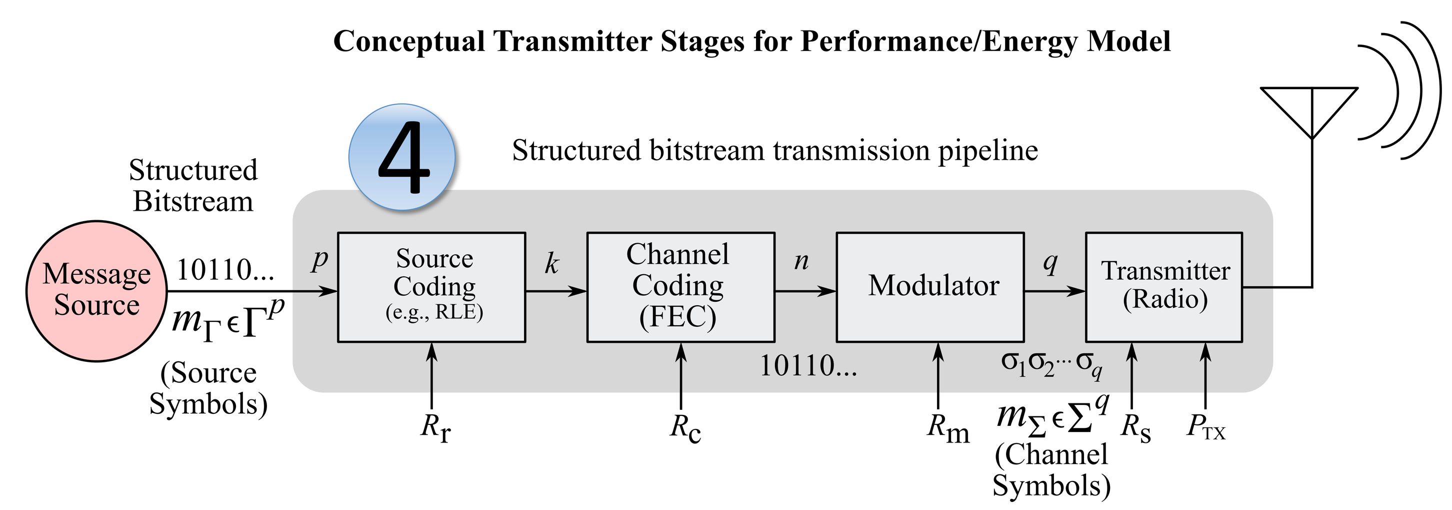
The above goals are achieved with proposed architecture (shown center/right):

- Feature-extraction and *pre*-diagnosis on biomedical signal via **D-stage (2)** to assign a 'score' representing *patient health state* called **Diagnostic Condition Level** (**DCL**).
- Signal is manipulated in the *wavelet* domain by the **Q-stage (3)** for eventual compression while working to preserve the features of clinical significance.
- Q-stage impact is evaluated via feature-based **Diagnostic Distortion Measure (DDM) (1)** to establish hard limits that would result in loss of clinical features by Q-stage.
- The resulting bitstream is sent to the transmission pipeline for further processing before eventual transmission **(4)**.
- All pipeline parameters in **(4)** can change in real-time as the patient health state (DCL) changes, balancing signal quality, urgency, and energy efficiency.

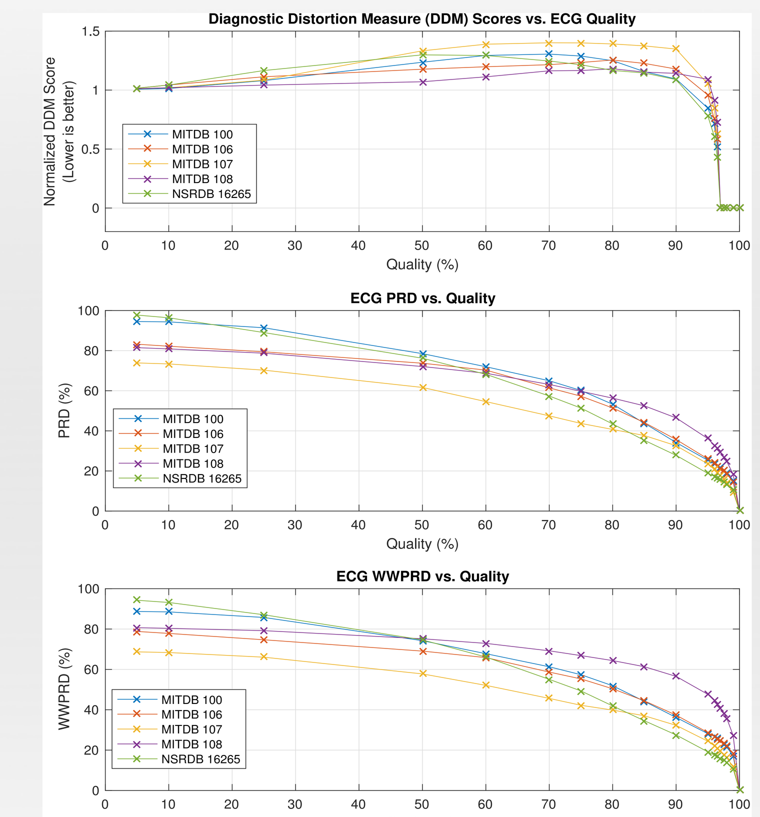
System Diagram for Physiologically-Aware Communication Architecture



Conceptual Transmitter Stages for Performance/Energy Model



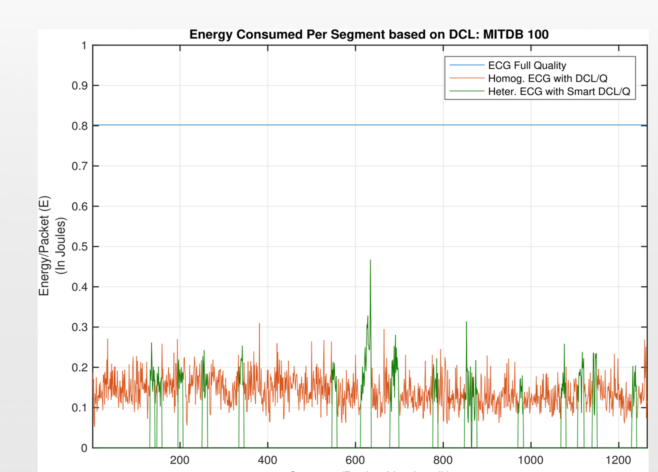
Sample-based Distortion Measures vs. Feature-Based Diagnostic Distortion Measure (DDM)

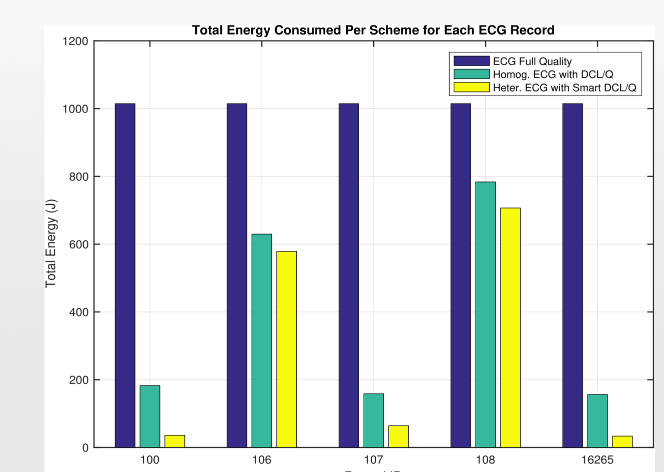


$$\Psi_{\vec{\mathbf{w}}}(\vec{\mathbf{\Gamma}}, \vec{\mathbf{\Gamma}}') = \frac{||(f(\vec{\mathbf{x}}) - f(\vec{\mathbf{x}}'))^T \cdot \vec{\mathbf{w}}||_2}{||f(\vec{\mathbf{x}})||_2}$$

1

Energy Profile



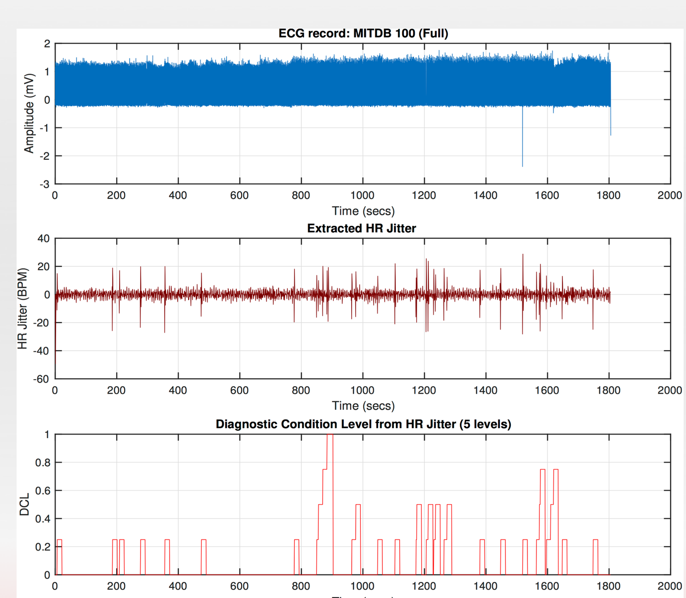


$$E_{m,\Sigma} = \frac{P_{TX}}{Rs} \frac{1}{R_c R_r R_m} \left(\ell(H) + \sum_{j=0}^{N_L} n_j r \right)$$

$$E_{m,\Sigma} = E_{m,\Sigma}^{(1,\delta(1))} + E_{m,\Sigma}^{(2,\delta(2))} + \cdots + E_{m,\Sigma}^{(N_S,\delta(N_S))} = \sum_{i=1}^{N_S} E_{m,\Sigma}^{(i,\delta(i))}$$

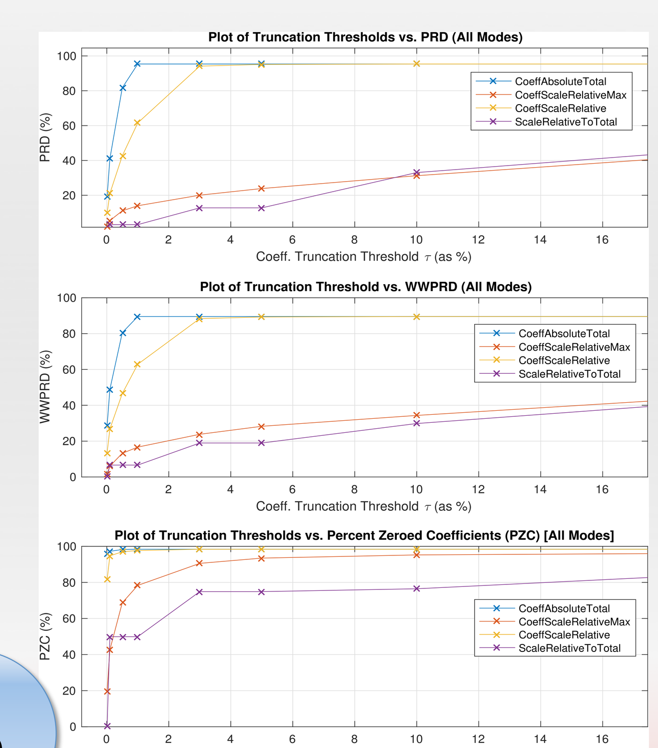
4

D-Stage Performance (Feat. Extraction and Pre-Diagnosis)



2

Q-Stage Performance and Compression Ratio Potential



3

Experimental Work

Experimental work was simulated and conducted in MATLAB:

- Experimental work focused on ECG-class signals as "proof-of-concept" behind research work.
- Five, 30-minute ECG records were used from **PhysioNet's** ECG database.
- Records: 100, 106, 107, 108 are of patients with various degree of *Arrhythmia*.
- Record 16265 is *Normal Sinus* for ground truth.
- Simulation work focused on characterizing energy by transmission pipeline in **(4)** given wireless transmission costs are much higher than computation costs.

Results

In no particular order:

- Plot **(2)** shows **D-stage** performance of ECG (top).
- The middle plot in **(2)** shows feature-extraction of patient health state in the form of *heart rate "jitter"* (middle).
- Bottom plot in **(2)** shows the DCL score, changing as a function of patient health state.
- Plot **(3)** shows performance of **Q-stage** comparing impact on signal quality in wavelet domain using four special "truncation modes".
- Some truncation modes are better at preserving signal quality with respectable gains in compression ratio.

(Cont'd)

- Plot **(1)** shows performance of feature-based **diagnostic distortion measure** (**DDM**).
- DDM allows us to actually "observe" when features of clinical significance actually disappear (top) by Q-stage effects.
- It compares DDM against sample-based distortion measures (e.g., PRD and WWPRD).
- Plots in **(4)** show energy performance of transmission pipeline.
- Left plot in (4) shows how energy changes for each packet transmitted as function of patient health state in a variety of modes: RAW mode, and *our* methods (homogeneous and heterogeneous data).

(Cont'd)

- Right plot in **(4)** shows *total* energy consumption for all five records using different transmission modes.
- Energy savings by factor of 30 are realized.
- This translates into proportional reduction in data.

Conclusion

This architecture is generalizable to class of biomedical signals. It prevents large volume of biomedical data to be generated; uses patient state to control almost any system parameter; achieves significant energy savings, helping to extend the lifetime of the device for medical-IoT applications.