

COMPSYS 705 Assignment 1 (part 1)

UPPAAL Modeling and Verification

1 DDD mode pacemaker (Weighting: 15%)

Your task is to create a model of DDD mode pacemaker using UPPAAL. The created model shall be verified using UPPAAL.

1.1 Model Description

The heart model, including two components of “Random_Atrium” and “Random_Ventricle”, has been given as shown in Fig. 1.

- Random_Atrium:
 - Inputs: AP;
 - Outputs: APulse;
 - Local clocks: x , $x \in [\text{Aminwait}, \text{Amaxwait}]$
 - `const int Amaxwait = 1200;`
 - `const int Aminwait = 1;`
- Random_Ventricle:
 - Inputs: VP;
 - Outputs: VPulse;
 - Local clocks: x , $x \in [\text{Vminwait}, \text{Vmaxwait}]$
 - `const int Vmaxwait = 1200;`
 - `const int Vminwait = 1;`

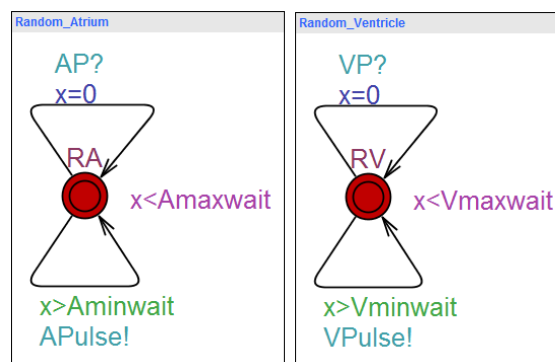


Fig. 1. A random heart model.

A DDD mode pacemaker is capable of sensing and pacing both the atrium and ventricle. The timing constraints include [1]:

- AEI: Atrial Escape Interval. This describes the maximum time interval between a ventricular event and the corresponding atrial event.
- AVI: Atrial Ventricular Interval. This describes the maximum time interval between an atrial event and the corresponding ventricular event.
- VRP: Ventricular Refractory Period. This defines the resting period for the ventricle after each ventricular event. Physiologically, ventricular events are not detectable by the pacemaker during the resting period. That is, if VPulse, generated by the heart model, occurs within VRP, it will be ignored by the pacemaker.
- PVARP: Post Ventricular Atrial Refractory Period. This defines the resting period for the atrium after each ventricular event. Physiologically, atrial events are not detectable detected by the pacemaker during the resting period. That is, if APulse, generated by the heart model, occurs within PVARP, it will be ignored by the pacemaker.
- URI: Upper Rate interval. This indicates the minimum time interval between two consecutive ventricular events.
- LRI: Lower Rate Interval. This indicates the maximum time interval between two consecutive ventricular events. In dual chamber mode, LRI time interval equals the summation of AVI and AEI. It serves as the lower bound for the heart rate, and hence the value of LRI is greater than URI.

Fig. 2 shows examples how the DDD mode pacemaker works at some heart conditions.

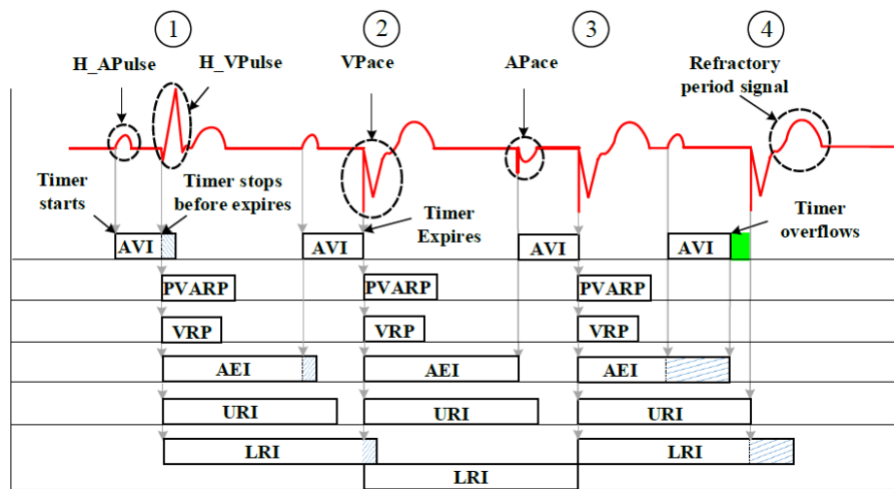


Fig. 2. The timing diagram of the DDD mode pacemaker [1].

- Waveform 1 indicates a normal heart behavior. We could observe that the related AVI timers stop before expiry, which shows a normal synchrony between an atrial event and the following ventricular event. Likewise, the behavior of AEI shows a normal synchrony between ventricular event and the coming atrial event.
- Waveform 2 presents the following situation where an artificial pulse (VPace) will be generated by the pacemaker if an intrinsic ventricular pulse is not sensed within the AVI interval. Also the LRI requirement is not violated.
- Waveform 3 features a situation where both AEI and AVI are expired. Consequently, to achieve the LRI requirement, both APace and VPace are produced.

- Waveform 4 presents an atrial event that is earlier than usual. It may cause a temporary fast ventricular rate if there is no upper limitation. The existence of URI defers the generation of VPace by extending the AVI interval to the length of the URI interval.

1.2 Instructions

- Use UPPAAL to build a DDD mode pacemaker to deliver treatments conforming to the timing constraints (const int AEI = 800; const int AVI = 150; const int VRP = 150; const int PVARP = 100; const int URI = 400; const int LRI = AEI + AVI;).
- Perform the verification of the following properties on the closed-loop system, composed of the heart model, the DDD mode pacemaker and monitors.

1. *The system is deadlock free.*
2. *A ventricular sense (VS) cannot be generated within VRP.*
3. *An atrial sense (AS) cannot be generated within PVARP.*
4. *The pacemaker never delivers a pacing pulse (AP) within AEI.*
5. *The pacemaker never delivers a pacing pulse (VP) within AVI.*
6. *The pacemaker never delivers a pacing pulse (VP) within URI.*
7. *The time interval between two consecutive ventricular events is always less or equal to LRI.*
8. *The pacemaker can deliver a pacing pulse (VP), where the time interval between this VP and its preceding atrial event is greater than AVI.*

1.3 Marking Criteria (Weighting)

- Modeling 60%
 - Use clocks to model the timing constraints. 60%
- Verification 40%
 - Modeling and verification of each property. 8×5%

2 References

- [1] Zhao, Yu, and Partha S. Roop. "Model-Driven Design of Cardiac Pacemaker Using IEC 61499 Function Blocks." *Distributed Control Applications: Guidelines, Design Patterns, and Application Examples with the IEC 61499 9* (2016): 335.
- [2] Jiang, Z., Pajic, M., Moarref, S., Alur, R., & Mangharam, R. (2012, March). Modeling and verification of a dual chamber implantable pacemaker. In *International Conference on Tools and Algorithms for the Construction and Analysis of Systems*(pp. 188-203). Springer, Berlin, Heidelberg.